This is a digital copy of a book that was preserved for generations on library shelves before it was carefully scanned by Google as part of a project to make the world's books discoverable online.

It has survived long enough for the copyright to expire and the book to enter the public domain. A public domain book is one that was never subject to copyright or whose legal copyright term has expired. Whether a book is in the public domain may vary country to country. Public domain books are our gateways to the past, representing a wealth of history, culture and knowledge that's often difficult to discover.

Marks, notations and other marginalia present in the original volume will appear in this file - a reminder of this book's long journey from the publisher to a library and finally to you.

Usage guidelines

Google is proud to partner with libraries to digitize public domain materials and make them widely accessible. Public domain books belong to the public and we are merely their custodians. Nevertheless, this work is expensive, so in order to keep providing this resource, we have taken steps to prevent abuse by commercial parties, including placing technical restrictions on automated querying.

We also ask that you:

+ *Make non-commercial use of the files* We designed Google Book Search for use by individuals, and we request that you use these files for personal, non-commercial purposes.

+ *Refrain from automated querying* Do not send automated queries of any sort to Google's system: If you are conducting research on machine translation, optical character recognition or other areas where access to a large amount of text is helpful, please contact us. We encourage the use of public domain materials for these purposes and may be able to help.

+ *Maintain attribution* The Google "watermark" you see on each file is essential for informing people about this project and helping them find additional materials through Google Book Search. Please do not remove it.

+ *Keep it legal* Whatever your use, remember that you are responsible for ensuring that what you are doing is legal. Do not assume that just because we believe a book is in the public domain for users in the United States, that the work is also in the public domain for users in other countries. Whether a book is still in copyright varies from country to country, and we can't offer guidance on whether any specific use of any specific book is allowed. Please do not assume that a book's appearance in Google Book Search means it can be used in any manner anywhere in the world. Copyright infringement liability can be quite severe.

About Google Book Search

Google's mission is to organize the world's information and to make it universally accessible and useful. Google Book Search helps readers discover the world's books while helping authors and publishers reach new audiences. You can search through the full text of this book on the web at `http://books.google.com/`

HARVARD UNIVERSITY

LIBRARY OF THE
MINERALOGICAL
LABORATORY

UNIVERSITY MUSEUM

DEPARTMENT OF THE INTERIOR

WATER-SUPPLY

AND

IRRIGATION PAPERS

OF THE

UNITED STATES GEOLOGICAL SURVEY

No. 20

WASHINGTON
GOVERNMENT PRINTING OFFICE
1899

UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

EXPERIMENTS WITH WINDMILLS

BY

THOMAS O. PERRY

WASHINGTON
GOVERNMENT PRINTING OFFICE
1899

CONTENTS.

	Page.
Letter of transmittal	9
Introduction by F. H. Newell	11
General statement	19
Apparatus	21
Angle of weather	22
Artificial wind	22
Dynamometer	23
Method of experiment	24
Starting forces	25
Journal friction	25
Comparative standard wheel	27
Results of original tests	28
Tables and descriptions of wind wheels	28
Wheel No. 1	28
Wheel No. 2	29
Wheel No. 3	31
Wheel No. 4	33
Wheel No. 5	34
Wheel No. 6	34
Wheel No. 7	36
Wheel No. 8	37
Wheel No. 9	37
Wheel No. 10	38
Wheel No. 11	38
Wheel No. 12	39
Wheel No. 13	39
Wheel No. 14	40
Wheel No. 15	40
Wheel No. 16	41
Comparative results with plain sails	41
Wheel No. 17	43
Wheel No. 18	43
Wheel No. 19	44
Wheel No. 23	46
Comparison of several wheels	46
Wheels Nos. 2 and 50	46
Wheels Nos. 18, 19, 20, 21, and 22	47
Wheels Nos. 24, 25, 26, 27, and 28	47
Wheels Nos. 29, 30, 31, 32, and 33	49
Wheels Nos. 19, 20, and 34	51
Wheels Nos. 35, 36, 37, and 38	51
Wheels Nos. 40, 41, 42, and 43	53
Wheels Nos. 40, 41, and 42	55
Wheels Nos. 35, 39, 40, and 44	57

Results of original tests—Continued. Page.
Comparison of several wheels—Continued.
Wheels Nos. 45, 46, 47, 48, and 49 ... 59
Wheels Nos. 2, 60, and 61 ... 61
Wheels Nos. 2, 49, 53, 54, 55, 56, and 57 ... 64
Wheels Nos. 2, 49, 51, 52, 58, and 59 ... 65
Sails at best angles of weather ... 65
Relations of three different velocities of wind ... 66
Automatic brake adjuster ... 67
Theory of the action of the wind upon the sails of windmills ... 69
Discussion of results ... 72
Thermometric and barometric influences ... 72
Construction of tables ... 73
Extreme results ... 73
Influence of outside wind ... 74
Standard of comparison ... 74
Corrections for axle friction ... 75
Aerial friction ... 76
Relation between speed and load ... 76
Best speeds for wind wheels ... 78
Best loads for wind wheels ... 78
Conical deflector in center of wheels ... 79
Air-cushioned sail surfaces ... 79
Obstructions on the back of sails ... 79
Waste of power due to the arms of wind wheels ... 80
Twisted sails ... 81
Deflectors in front of sails ... 81
Obstructions in front and in the rear of wind wheels ... 82
Maximum products in different velocities of wind ... 82
Starting forces and loads at the maximum in different velocities of wind ... 83
Speeds of unloaded wheels in different velocities of wind ... 83
Action of air on the sails of a wind wheel ... 84
Theoretical efficiency of the wind wheel ... 84
Theoretical useful effort of wind ... 87
Aerial resistance to motion ... 89
Best number of sails ... 90
Best relative areas of sail surface ... 90
Actual efficiency of the wind wheel ... 91
Work of variable wind with variable load ... 92
Regulation of wind wheels ... 92
Limitation to size of wind wheels on account of weight ... 93
Efficiency of wind wheels as affected by diameter ... 94
Height of towers ... 94
Multiplication of wind power ... 95
Power of a 12-foot wind wheel ... 95
Value of mathematical formulæ in experimental investigations ... 96
Index ... 97

ILLUSTRATIONS.

		Page.
PLATE I.	Windmill pumping water for irrigation	11
II.	Reservoir and garden	12
III.	Windmill and small reservoir	14
IV.	Small irrigation reservoir	14
V.	*A*, Homemade wind engine, as used on the Great Plains; *B*, The Defender windmill and water elevator	16
VI.	Elevation of apparatus used in wheel tests	20
VII.	Plan of apparatus used in wheel tests	20
VIII.	Plan and elevation of dynamometer	22
IX.	End views of dynamometer	24
X.	Windmill and reservoir	78
XI.	Windmill and reservoir	88
XII.	Windmill on low tower on the Great Plains	94
FIG. 1.	Vertical section through reservoir and outlet	12
2.	Windmills and circular reservoir	13
3.	Steel windmill and tower carrying tank	14
4.	Irrigating ditch leading from earth reservoir filled by windmills	16
5.	Distribution of water to small beds	17
6.	Distribution system adapted to irregular land	17
7.	Elevation and section of wheel No. 2	30
8.	Outline of area not available	31
9.	Elevation and section of wheel No. 3	32
10.	Dimensions of sails of wheel No. 3	33
11.	Angles of weather of sails of wheel No. 3: *A*, Angle at inner ends of sails; *B*, Angle at outer ends of sails	33
12.	Elevation and section of wheel No. 6	35
13.	Dimensions of sails of wheel No. 6	36
14.	Dimensions of sails of wheel No. 18	44
15.	Elevation and section of wheel No. 19	45
16.	Elevation and section of wheel No. 24	48
17.	Elevation and section of wheel No. 29	50
18.	Elevation and section of wheel No. 35	52
19.	Dimensions of sails of wheels Nos. 35, 36, 37, and 38	53
20.	Elevation and section of wheel No. 40	54
21.	Dimensions of concave sails of wheels Nos. 40, 41, 42, and 43	55
22.	Elevation and section of wheel No. 39	56
23.	Dimensions of sails of wheel No. 39	57
24.	Elevation and section of wheel No. 44	58
25.	Elevation and section of wheel No. 48	60
26.	Dimensions of sails of wheels Nos. 45, 46, 47, 48, and 49	61

Page.
FIG. 27. Elevation and section of wheel No. 60 62
28. Elevation and section of wheel No. 61 63
29. Dimensions of sails of wheel No. 61 with obstruction on back 64
30. Action of wind on a sail 70
31. Action of air on the sails of a wind wheel 84
32–35. Theoretical efficiency of the windmill 85
36–39. Theoretical useful effort of wind 87–88

LETTER OF TRANSMITTAL.

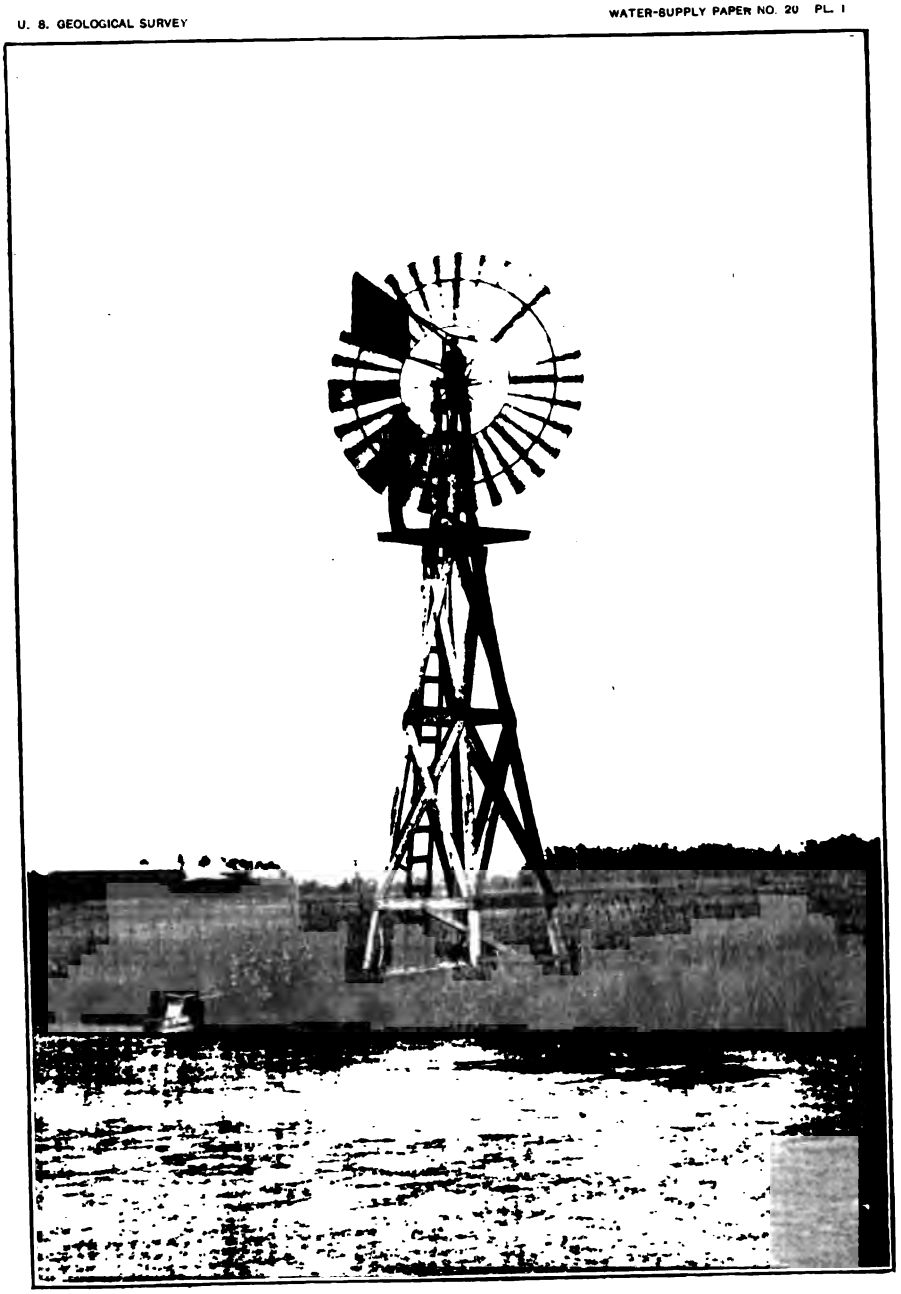
DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF HYDROGRAPHY,
Washington, July 15, 1898.

SIR: I have the honor to transmit herewith a manuscript entitled Experiments with Windmills, prepared by Mr. Thomas O. Perry. These experiments, as described by Mr. Perry, were carried on during the years 1882 and 1883 for the United States Wind Engine and Pump Company, of Batavia, Illinois. As a result of these experiments radical changes and improvements were made in the windmills. As a matter of business policy the company did not desire that the results of these tests should be made known for some years. After the expiration of a certain time, however, the data have been placed at the disposal of the public through the kindness of the officers of the company and the efforts of Mr. Perry. Although as the result of this work great changes have been made in windmills, many of the suggestions made have not yet been put into practice and may serve as a foundation for further work along this line. The importance of the windmill as a means of utilizing the water resources of a part of the country is so great that all available information on the subject should be diffused and brought to the attention of persons who can make use of the facts. I respectfully request, therefore, that this manuscript, with a brief introduction, be printed as one of the series of pamphlets on water supply and irrigation.

Very respectfully,

F. H. NEWELL,
Hydrographer in Charge.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.



WINDMILL PUMPING WATER FOR IRRIGATION.

INTRODUCTION.

By F. H. NEWELL.

During the progress of investigation of the extent to which the arid lands can be reclaimed by irrigation and of the related question of the occurrence of water underground attention has been continually drawn to the practical methods of bringing the underground water to the surface. Throughout a great part of the arid and semiarid region there are localities where water can be obtained at a short distance from the surface. The amount, although not large in the aggregate when compared with the quantity in some notable stream or lake, is yet inexhaustible by the ordinary methods of pumping. If, therefore, this water which exists from 10 to 50 feet beneath the surface could be cheaply raised, it would be practicable to utilize for agriculture tracts which otherwise have little or no value.

The irrigation of 20 acres in the midst of a section or township of land is, figuratively speaking, a mere drop in the bucket; but the reclamation of this small area generally means the utilization of adjoining lands. If, for example, 20 acres of some forage crop like alfalfa is made possible, this will result in obtaining a considerable amount of winter feed used in the sustenance of a herd which can be pastured upon the surrounding dry land. The successful cultivation of this 20 acres may thus directly or indirectly support a family, and, with increased experience and adaptation to the surrounding conditions, the family may in turn give place to a rural community. Given the existence of sufficient water underground to irrigate the 20 acres, the first question is that of ways and means of bringing the water to the surface.

The force which is ever present, making itself persistently felt throughout the Great Plains region, is the wind, which blows almost continuously. It carries the dust before it, cuts out the traveled roads, carries away the fine earth of the tilled fields, and builds up a fine loess, almost everywhere to be found. The wind, which has so long been considered as an annoyance and mischief-maker, has sufficient strength to perform the work of bringing water to the surface, if only suitable means of directing its energy can be discovered.

The windmill is the best-known method of converting wind energy into work. In one form or another it has been used from times ante-

dating the dark ages. In the twelfth century windmills, built either by individuals or by communities, were common. Some of these mills were of enormous size. In the German type the whole building on which the mill was placed was constructed in such a manner as to turn on a post in order to bring the sails into the wind. In the Dutch form the building was fixed, but the head of the mill could be turned into the wind. The most notable use of these early mills was in Holland, where the land was drained by pumping water from behind the dikes into the sea. In 1391 the bishop of Utrecht, holding that the wind of the whole province belonged exclusively to him, gave to the convent at Windsheim express permission to build a windmill wherever it was thought proper. In so doing he overruled a neighboring lord who declared that the wind in the district belonged to him. Three years later the city of Haarlem obtained leave from Albert, Count Palatine of the Rhine, to build a windmill, using the wind of the country.[1]

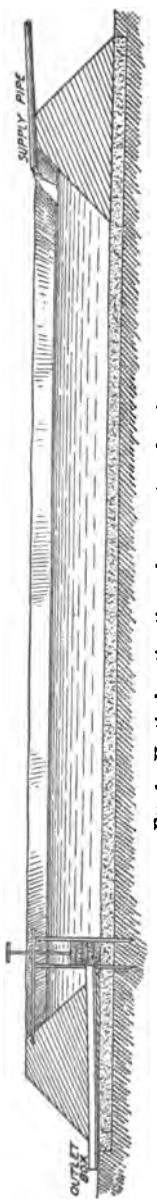


FIG. 1.—Vertical section through reservoir and outlet.

The huge, clumsy windmills of European make, one of which was erected at Lawrence, Kansas, within the memory of the present inhabitants, have within a few decades given place in this country to the light, rapidly running forms. Thousands of these have been made by various firms throughout the country. At first wood was used almost exclusively, but this is being rapidly displaced by metal, especially by thin steel plates and forgings. Although millions of dollars have been invested in the manufacture and purchase of mills and much attention has been given to the mechanical details and the saving in weight and cost, yet comparatively little study has been bestowed upon the actual efficiency of the various forms and upon their development toward theoretical ideals.

A view of gardens cultivated by water pumped by windmills is shown in the accompanying plate (Pl. II). This picture has been taken from a windmill platform. In the foreground is a small reservoir, divided by a bank in the middle, so that one part may be used independently of the other. The part nearer the observer is the older; the second part is a recent addition, rendered necessary by the increase of the area cultivated. Without windmills the cultivation of the tract of country shown in this picture would be impossible. It is doubtful if a single cow could find subsistence on the area which now supports a family.

[1] The Windmill as a Prime Mover, by Alfred R. Wolff, p. 51.

RESERVOIR AND GARDEN.

Another small reservoir and windmill is shown on Pl. III. This reservoir is in the corner of a small suburban truck farm, to which it furnishes water both for vegetables and trees. The owner has stocked a small pond with fish and from it obtains an ample supply for his own use. On the right-hand side is shown the outlet gate, through which water is discharged into a ditch, and that in turn empties into furrows running near the fruit trees and traversing the cultivated ground.

In fig. 1 is given a section through one of these small reservoirs, showing at the bottom the puddled earth or clay that prevents the water from seeping into the adjacent ground. On this puddled earth the banks are built at a height of from 4 to 10 feet. These are usually built by plowing and scraping up the earth from the outside, the tramping of the horses and the men serving to consolidate it. When the bank has been built to the proper height it is smoothed and sodded. On the right-hand side of the figure is the pipe or wooden flume from the windmill, and on the left-hand side is shown the outlet box, which is usually built of 2-inch plank. This is closed by some simple form of wooden gate or valve, either lifted by means of a screw or hinged so as to open outward, and is held in place by the pressure of the water against it.

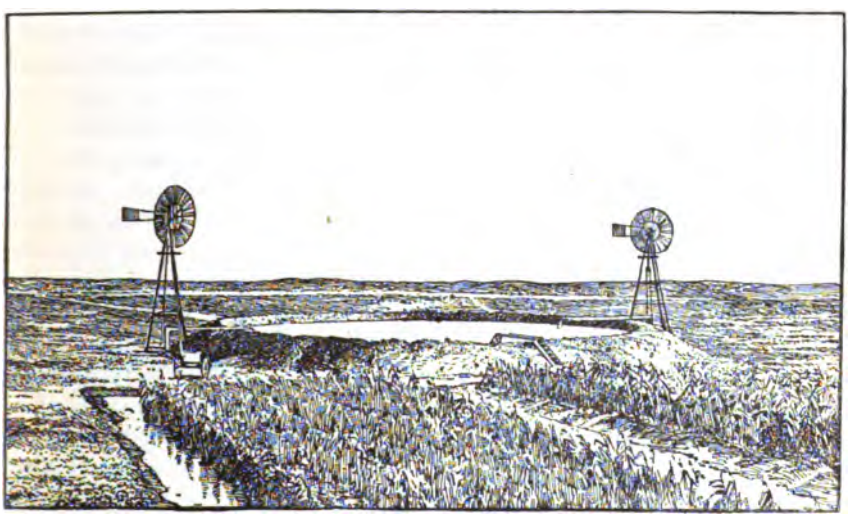


FIG. 2.—Windmills and circular reservoir.

The square reservoir is the form usually adopted. The mills, as in the other cases, are placed on each side, pumping through short wooden flumes over the bank. These reservoirs are not only used for holding water for irrigation, but, as before stated, with a little care serve as ponds for raising fish.

A view of one of these small square reservoirs is shown on the accom-

panying plate (Pl. IV). The banks are obscured by the luxuriant growth of weeds. The surface of the water is a little higher than the general level of the land, so that a supply can be drawn by gravity directly to the adjacent fields.

Fig. 2 gives a nearer view of one of these earth reservoirs, which in this case has been built nearly circular in form. The two windmills which supply the water are placed upon opposite sides, in order that the pumps may be as far apart as possible. In many instances three or even four mills, each of moderate size, are placed around a reservoir of considerable size. The banks, made of earth, are covered with sod to protect them from washing by the rain and by the waves during times of high winds.

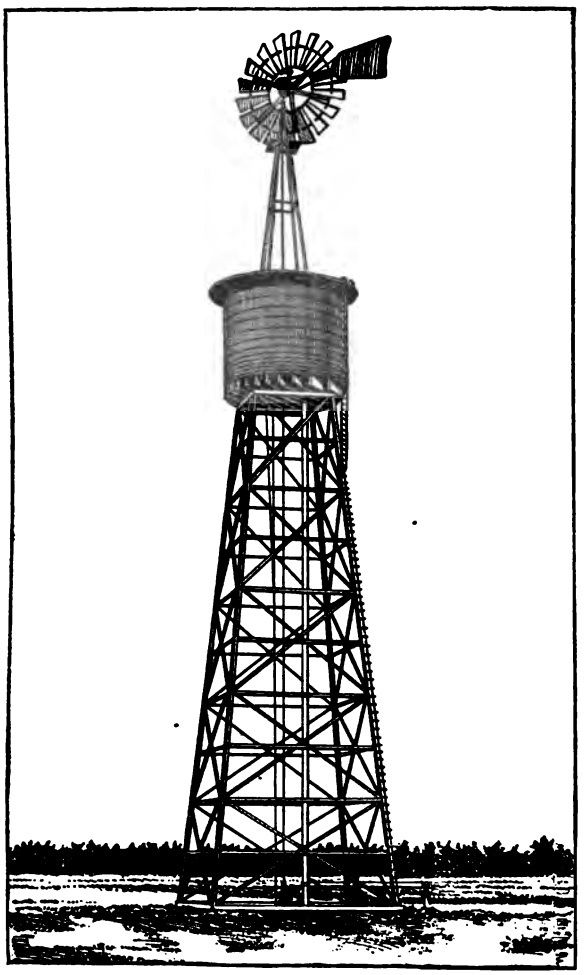
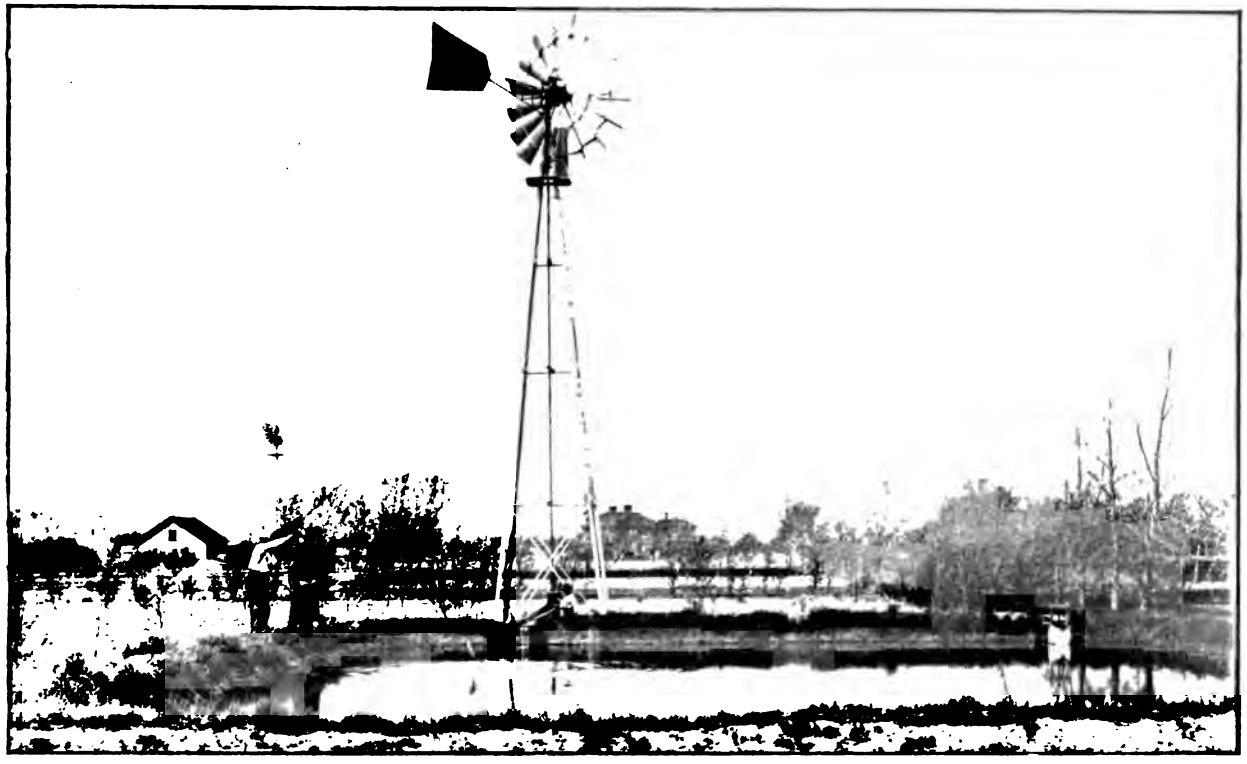


FIG. 3.—Steel windmill and tower carrying tank.

Fig. 3 represents an adaptation of a windmill for use in domestic water supply or for furnishing water to a village or small town under considerable pressure. The wind engine is erected on the top of a high steel tower, which also supports a wooden tank with suitable cover to protect the water from loss by evaporation. This device is generally employed by railroad companies at stations on the Great Plains, where the wind may be depended upon to force a sufficient supply into the tank for use by locomotives or for the railroad shops and offices. Many towns also depend for their water supply upon a windmill pumping water into an elevated tank, particularly where the general surface is so nearly level



WINDMILL AND SMALL RESERVOIR.

SMALL IRRIGATION RESERVOIR.

that it is impossible to construct a small earth reservoir within reasonable distance of the principal buildings.

The device shown in Pl. V, *A*, which has been employed to a considerable extent in the Great Plains region, is usually constructed by the owners. The merit of the device is its cheapness. It may be built mainly of old lumber and other material that can often be found about the farm, such as axles or other gear from old farm machinery, bale wire for staying the sails, and pieces of wood or metal which may be classed as old junk. The machine can not be recommended on the ground of efficiency or economy. If a farmer has sufficient capital to purchase and erect a good windmill he will undoubtedly succeed better than by spending his time in making the cheaper device. On the other hand, in situations where, as is often the case in a dry region, the farmer has lost crops year after year, has exhausted his resources, and is on the verge of bankruptcy, a contrivance of this kind may serve to save a small crop and give him a new start. In such instances there usually will be found pieces of broken-down machinery about the farm. Time and labor are commonly of little value where the ordinary farming operations have been unsuccessful, so that by the exercise of a little ingenuity the material and energy that otherwise would be wasted may be turned to advantage.

The mill or engine consists of a shaft of wood or iron placed horizontally and supported at each end. Upon this sails are fastened by arms extending out at right angles. On each end of the shaft is attached a crank, and each of these cranks in turn drives some simple form of homemade pump. The lower half of the mill is boxed in, and thus forms a small building without roof, above which project the arms carrying the sails.

As illustrating another homemade device, Pl. V, *B*, has been introduced. This mill and water elevator, invented by the owner, has been successfully used to furnish water for irrigation, and, although not by any means an economical device, nor one that can be recommended, it has served its purpose. In other words, while as a rule it is economical to purchase the best, there are circumstances and times when for special reasons the best mill can not be had, but it is still practicable to construct a machine which will accomplish the desired end, that of getting water from the ground upon the land.

These examples might be almost indefinitely multiplied, but are sufficient to demonstrate the principle that with energy and ingenuity a start toward irrigation can be made. When, however, some experience has been had in irrigation and newer mills are being procured, it is highly essential for continued success that something better than the ordinary form of mill be obtained. Many of these have been designed for some other purpose than that of raising large quantities of water through a short distance for irrigation. Some, for example, have been built with the idea of pumping a small quantity from great

depth for watering stock. Such mills, as a rule, do not fill the requirements of the irrigator. Thousands of windmills are in use and thousands more will be purchased, involving expenditures on the part of farmers aggregating millions of dollars. A saving of even a small percentage in cost and economy is therefore a matter of considerable importance in the continued development of the water resources of the country.

Fig. 4 shows two windmills so arranged as to pump into a reservoir built of earth, placed upon the highest part of a farm. Running night and day the pumps supply such a quantity of water to the reservoir that when needed a considerable volume can be drawn at once, filling

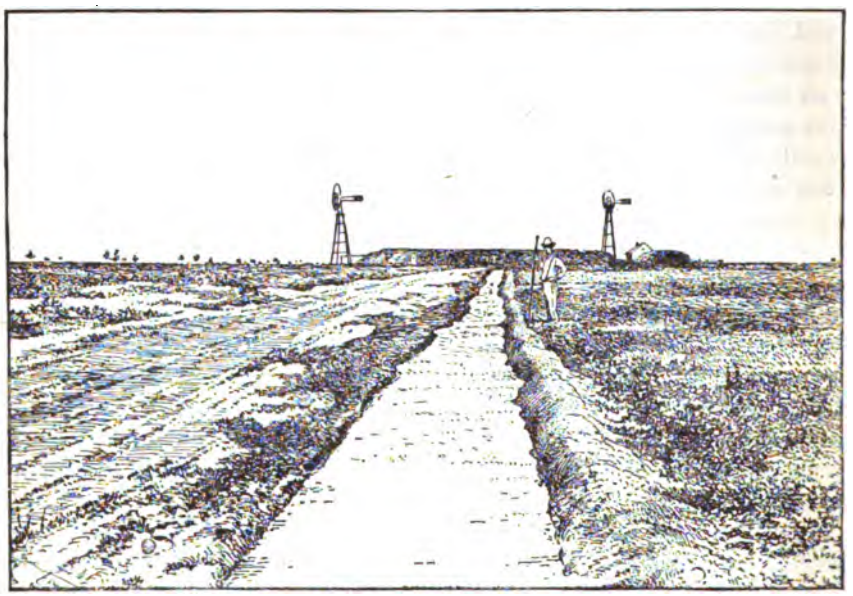


FIG. 4.—Irrigating ditch leading from earth reservoir filled by windmills.

a ditch of as large size as is ordinarily built for irrigating a field of from 10 to 20 acres.

Fig. 5 illustrates one of the methods used to distribute small quantities of water, such as may be had from the tank or reservoir of a windmill. In the drawing the banks are represented as made of cement or of wooden planks, such as are used in portions of California, where water has especial value. The usual practice, however, within the Great Plains region is to make the ditches of earth and to place the little gates in wooden frames. Sometimes instead of using gates the irrigator controls the water by shoveling earth into the ditches and furrows, backing up the water until it overflows the bank or comes out through on opening made by means of the shovel. As shown in the figure, the water flowing in the main stream from right to left is checked by small gates and forced to flow laterally through furrows,

A. HOMEMADE WIND ENGINE, AS USED ON THE GREAT PLAINS.

B DEFENDER WINDMILL AND WATER ELEVATOR

and is again checked in these and forced out upon the beds lying on each side of the furrow. When a certain portion is wet the small gates are adjusted so as to force the water over other portions.

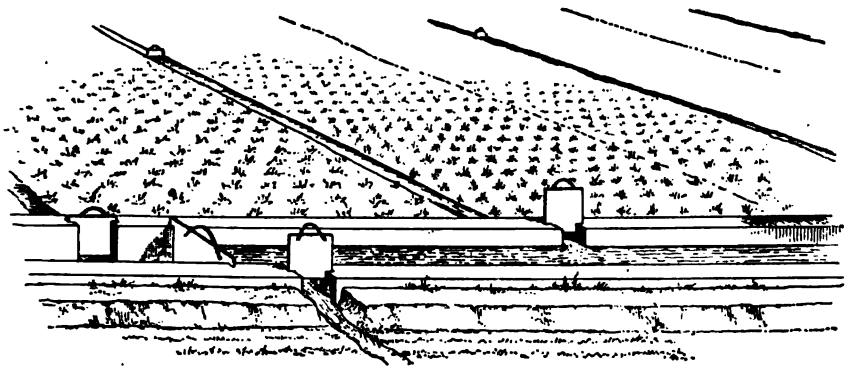


FIG. 5.—Distribution of water to small beds.

Where land has a decided fall or is rolling and it is too expensive to terrace, a system of distributing the water must be devised suited to the contour of the ground. In the case shown by the accompanying figure (fig. 6) the water enters the distributing ditches at the upper left-hand

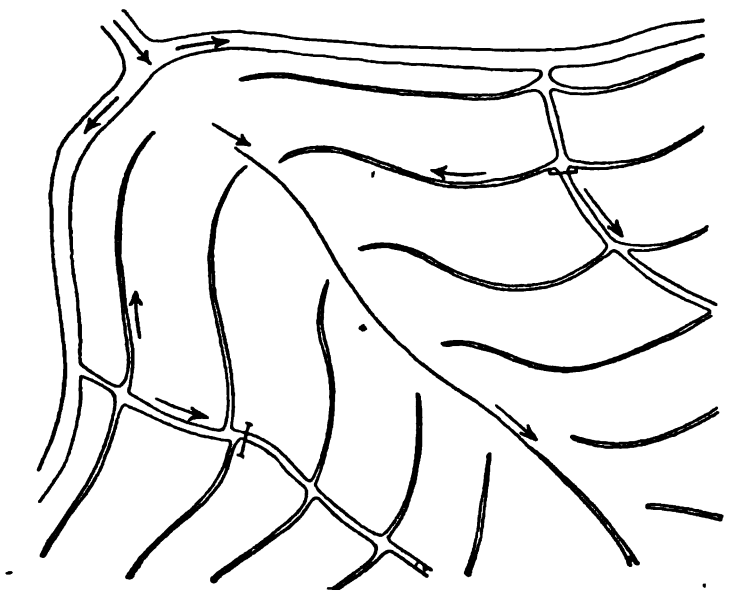


FIG. 6.—Distribution system adapted to irregular land.

corner and, dividing, flows through these and again into still smaller ditches, from which it is turned laterally into furrows. The flow is checked from point to point by little dams or temporary obstructions of

earth. After the water passes out upon a field any surplus is caught by a small trench shown in the figure as trending diagonally toward the right-hand lower corner, and from this in turn the water can be caused to flow out upon the lower fields, so that the excess or seepage from the higher portions is not wasted but is employed in the irrigation of the lower parts of the farm.

There are many other devices by which water pumped by windmills may be stored and distributed, but those briefly described above are among the most common. It is sufficient at this time to make mention of these in order to bring out the fact that experiment has demonstrated that it is practicable to irrigate land by water pumped by windmills. Many farmers in various parts of the United States are dependent for their living on this system of agriculture, and others are seeking to gain knowledge by which they may better their condition by providing a water supply for use in times of drought. This is true not only of the West, but of the East and the South, especially in regions where the soil, though fertile, is light and becomes dry if the rains do not occur with great regularity. Even on the Atlantic seaboard the early truck farmers are experimenting with devices of this character, copying methods which have already proved successful in Kansas. Modifications in mills and other machinery are doubtless necessary to suit local conditions. For a given purpose one mill may be far better than another, and of two wind engines similar in cost one may be actually worth two or three times as much as the other.

The dynamometric experiments carried on by Mr. Perry, as described in the following pages, have brought out many important points upon which depend the relative efficiency of various mills and the advantages of one type over another. Some of these points have already been considered and made use of in mills now on the market, while others of equal or greater importance are awaiting practical application and ingenuity. It is hoped that by the publication of these facts interest will be aroused and inventors will be stimulated to continue work along various lines, leading to further improvement and to a consequent cheapening of the cost of raising water by wind power.

EXPERIMENTS WITH WINDMILLS.

By THOMAS O. PERRY.

GENERAL STATEMENT.

The experiments with wind wheels described in the following pages were commenced June 1, 1882, and concluded September 15, 1883. At that time wind wheels in this country were nearly all made with narrow wooden slats for sails, set at various angles with the plane of the wheel, ranging from 35 to 45 degrees.

The slats were usually placed as close together as possible without having their projections on the plane of the wheel overlap. The proportions of sail surface and their angles of weather were apparently arrived at without any well-defined purpose. The only experiments made in the United States, so far as could be learned, related to starting forces only. They did not include the measurement of work in foot-pounds. The only well-defined experiments with wind wheels, the records of which were available, were those made in England by John Smeaton, F. R. S., about one hundred and twenty-five years before. Smeaton's paper, On the Construction and Effects of Windmill Sails, was read before the Royal Society May 31 and June 14, 1759, and to this day has remained the only definite available source of information on the subject treated. The paper was republished in Tredgold's Tracts on Hydraulics, a copy of which was received before these experiments were commenced.

It had been especially noted that Smeaton's angles of weather were much less than those in common use in this country, and note had also been taken of his statement to the effect that the work of a wind wheel is not increased, but diminished, by crowding it with sails so that their total surface exceeds about seven-eighths of the circular area containing them. The universal practice here was to crowd the wheel with slats until the total sail surface exceeded the total area of the annular zone containing them by more than one-fifth of the whole zone; according to Smeaton, this was adding to the greatest possible effective sail area more than 39 per cent additional area of worse than useless surface. If a large part of the material could be saved, and at the same time a considerable increase in power be effected, no slight

gain would be secured. Smeaton's experiments were made so long ago that they were disregarded, if they were ever noticed, by the builders of modern wind wheels. Our experiments fully confirmed Smeaton's results in regard to the greatest effective amount of sail area, although we do not necessarily accept Smeaton's judgment that it is not profitable to increase the total area of sails beyond about 37 per cent of the annular zone containing them.

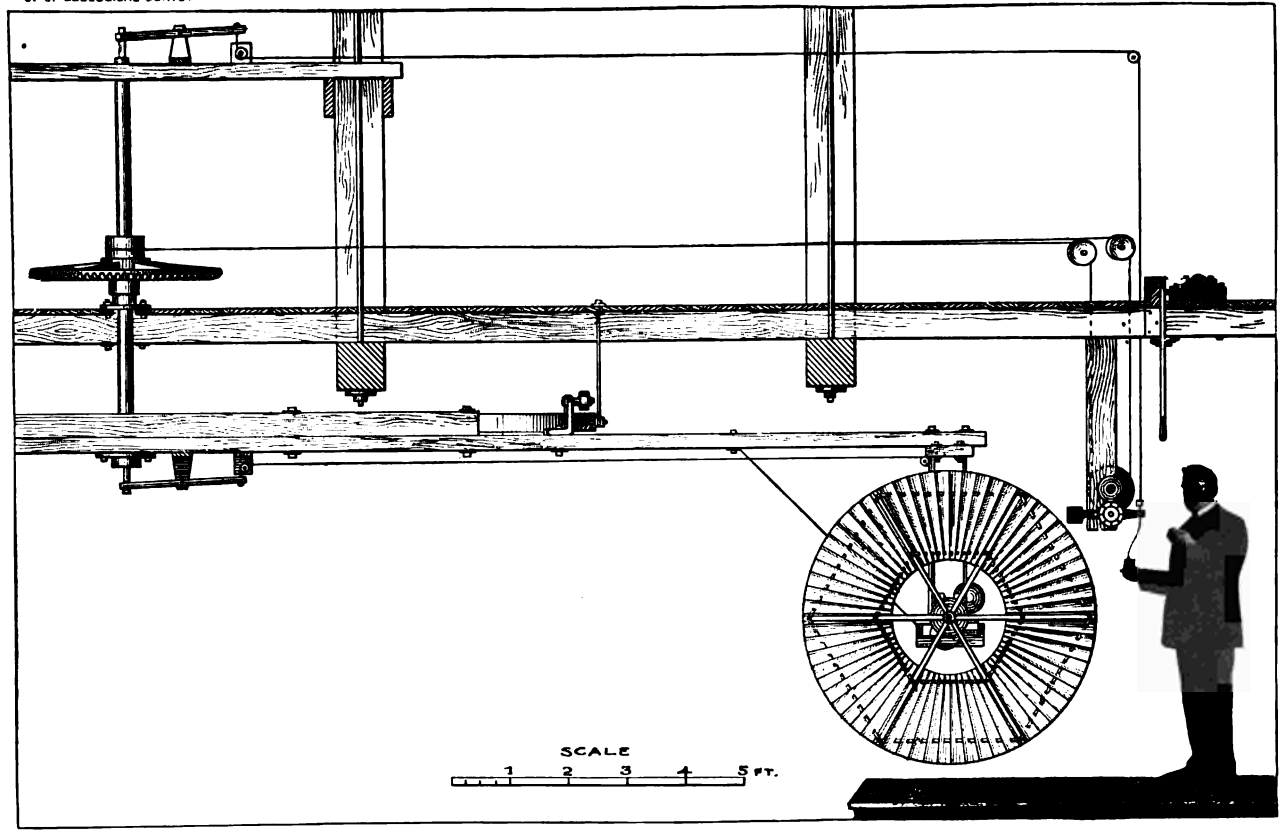
In wheel No. 3 we followed closely Smeaton's angles of weather, but did not obtain so good results as with greater angles. In fact, we were not able to obtain the best results with weather angles so small as Smeaton's in any of our wind wheels. Nor did our sail speeds, as compared with wind velocity, nearly approach the speeds obtained by Smeaton. Even our unloaded wheels did not show the sail speed attained by the best of Smeaton's wheels when loaded for maximum work.

This difference in the ratio of sail speed to wind velocity constituted the greatest disagreement between his results and ours. Our loads at the maximum of work were smaller as compared with greatest loads, and the speeds of revolution at maximum work as compared with speeds of unloaded wheels were smaller for our wheels than for Smeaton's. The general laws established by Smeaton, as enunciated in his eight "maxims," were substantially confirmed by our experiments. The law of cubes pertaining to maximum products and the law of squares pertaining to greatest loads, or starting forces, were more exactly fulfilled in our experiments than in Smeaton's. The differences in results as regards angles of weather, speeds, and best loads might have been due to differences in the construction of the wheels.

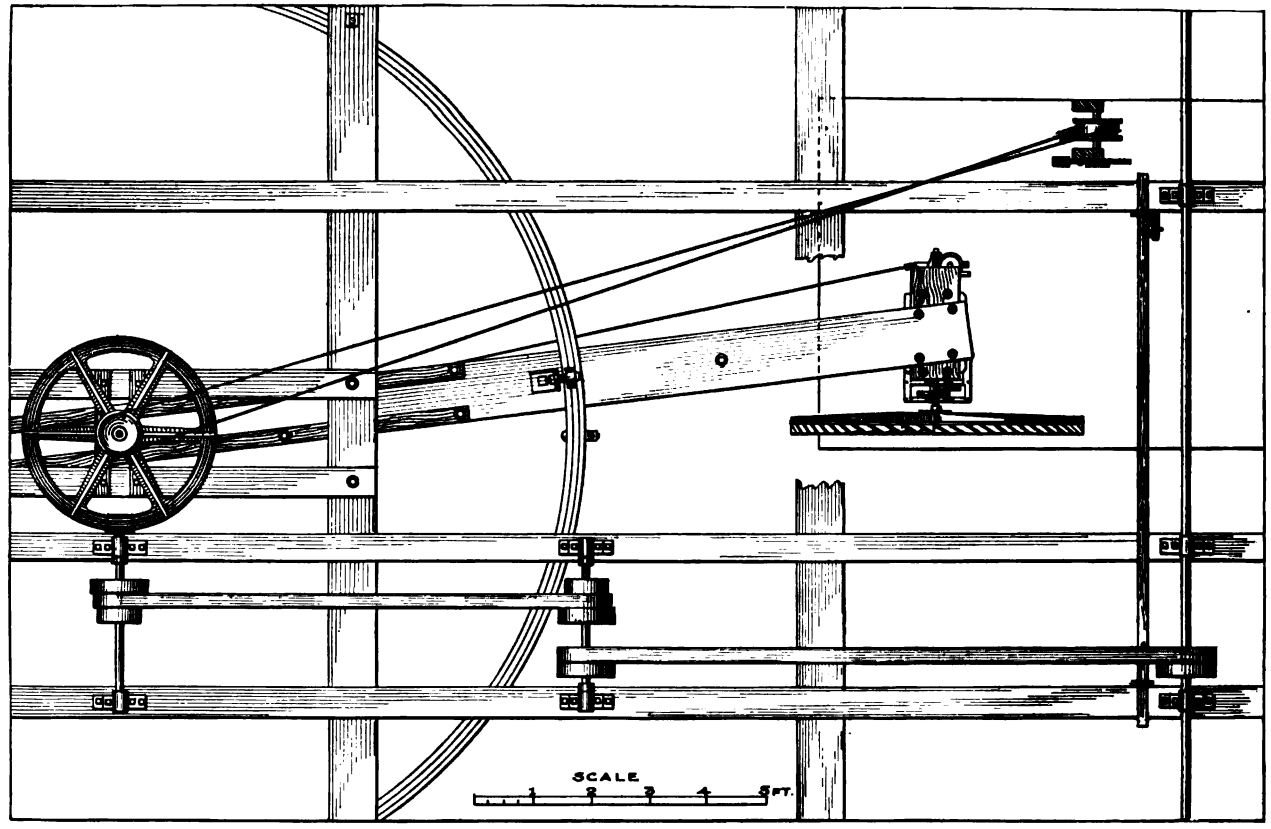
Smeaton constructed his wheels after the manner of windmill construction in his time, and we constructed our wheels mostly after the methods adopted by American manufacturers at the time we experimented. Our methods of experiment were similar, though Smeaton's experiments were conducted on a much smaller scale with smaller wheels, and his appliances generally were crude as compared with our own.

Smeaton allowed about one-eighth of his total applied load as the equivalent additional load due to friction. This friction, as Smeaton determined it, was in reality friction at starting only, and it must have been much in excess of the friction under the rapid revolutions of his wheels, and helped considerably to swell his products.

Still another allowance must be made in comparing Smeaton's efficiencies with ours, on account of the relative shortness of the sweep, which carried his wheels in a circle against still air. The velocity of the centers of his wheels was taken as the equivalent velocity of wind. As a matter of fact, some point beyond the center of the wind wheel, farther away from the axis of the sweep, should have been taken to represent wind velocity. The distance from the axis of Smeaton's



ELEVATION OF APPARATUS USED IN WHEEL TESTS.



PLAN OF APPARATUS USED IN WHEEL TESTS.

sweep to the extremity of his sail as it revolved was, when greatest, nearly double its least distance, and the energy of the wind acting on the tip of his sail was more than seven times as great at the maximum as at the minimum distance. To compute accurately the total wind energy intercepted by the wheel, after taking into account the various velocities of impingement, would be an interesting problem in integral calculus.

The differential expression for work is easily found, but the integration is not so simple. An approximate calculation shows that the wind energy intercepted by Smeaton's wheel was more than 7 per cent in excess of what it would have been had all points of the wheel met the air with the same velocity as at the center. The difference is not so large as one would expect from the great difference in energy at extreme positions. We doubt whether anything should be deducted from Smeaton's products on this account, for only a very limited portion of the sails could have a proper relative velocity with respect to the wind. Our wheels were, of course, similarly affected, although in considerably less degree.

Weisbach's theoretical formulæ for wind action, if correct, would cast a cloud over Smeaton's results; for he concludes his rather elaborate mathematical discussion with these words: "According to these experiments [Smeaton's] the action of the wind in general upon sail wheels is greater than is given either by the theory or by Coulomb's experiments." Coulomb's very incomplete experiments seem to have been a great source of consolation to those mathematicians whose theories would not permit the realization of efficiencies so great as Smeaton obtained.

Our own experience with wind wheels in actual use, in widely different lines of work, and the testimony of many persons using them, convince us that the efficiencies we obtained and which Smeaton obtained in artificial wind are not so great as those commonly obtained now in natural wind. We consider our experiments valuable principally on account of the comparisons made and the insight they afford into the causes of waste. Through the courtesy of Mr. H. N. Wade, manager of the United States Wind Engine and Pump Company, of Batavia, Illinois, we are enabled to reproduce the original records of our experiments on wind wheels as they were made in 1883.

APPARATUS.

Our experiments were conducted in a room about 36 feet wide, 48 feet long, and 19 feet high from floor to roof trusses.

Pls. VI and VII represent, in elevation and plan, as a whole, the apparatus that was used and show portions of the roof trusses underneath which the sweep was suspended. The rear end of the sweep, not shown, carried a counterweight, which caused the whole apparatus to balance on the central shaft. Two rollers carried by the sweep on

opposite sides of the suspending shaft ran lightly over a large circular track and prevented vertical oscillations. Pls. VIII and IX present enlarged views, showing the details of the dynamometer and its method of application.

These four plates and the illustrations of wind wheels Nos. 3, 6, 19, 24, 29, 39, 40, 44, 60, and 61 were recently prepared from data in our possession. The illustrations of wheels Nos. 2, 35, and 48 are reproductions of the drawings made for the original records, as are also all the other illustrative figures which are shown in connection with the original records. In computing the figures denoting efficiencies, shown in connection with the illustrations of wheels Nos. 3 and 6, axle friction was called 0.15 pound instead of the 0.3 pound given in the tables, as explained under the heading "Corrections for axle friction."

In these two cases, and also in computing the efficiency of wheel No. 2, allowance was made for temperature as recorded and for atmospheric density, according to the records of the United States Signal Service station at Chicago for 2 p. m. on the days of experiments.

The efficiencies shown in connection with all the other illustrations of wind wheels were obtained by simply multiplying the efficiency for No. 2 by the ratios of products given in the various tables where direct comparison with No. 2 is shown.

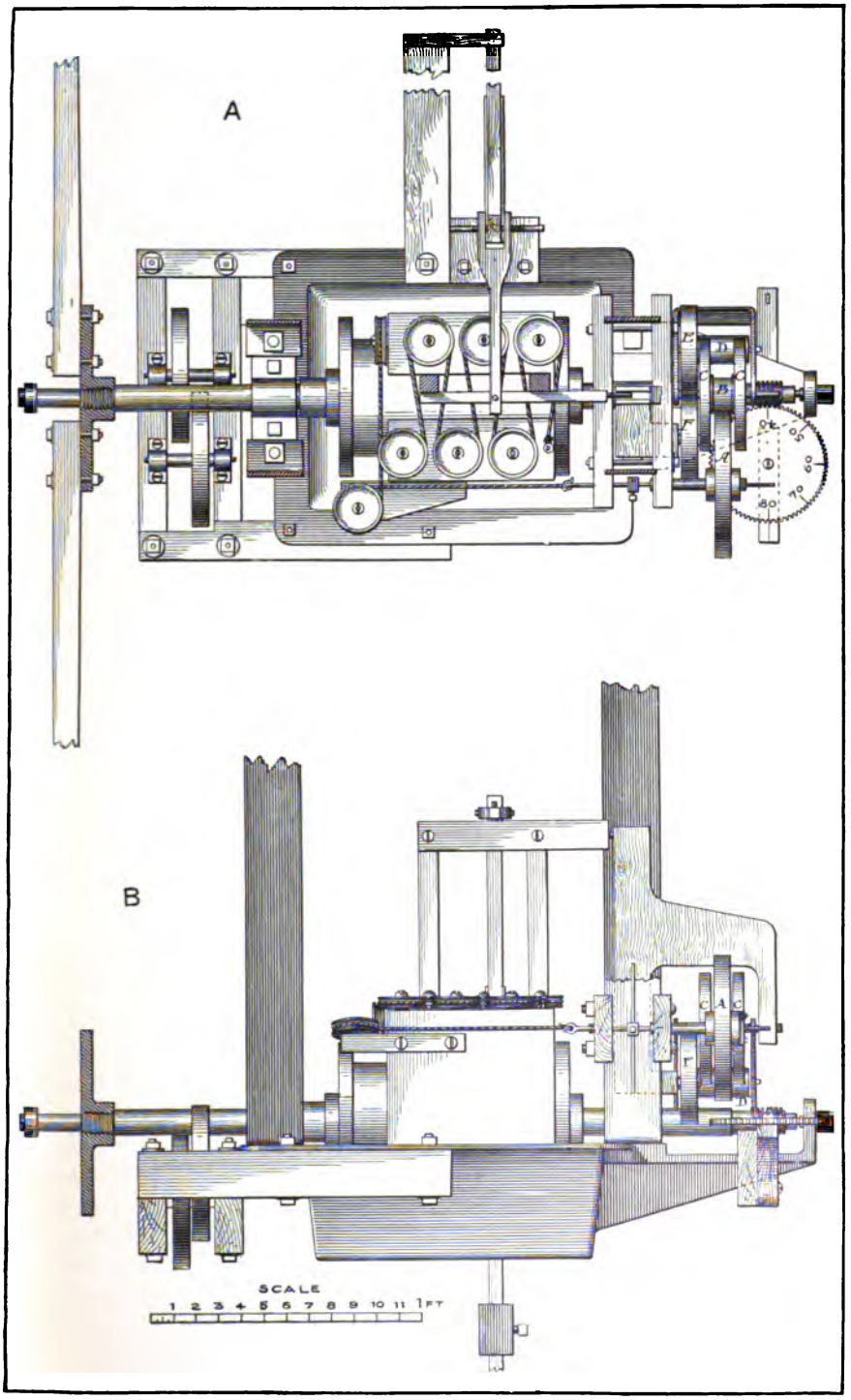
The original records of 1883, immediately following, end on page 72. The comments following page 72, including the tables on pages 74 and 77, have recently been prepared.

ANGLE OF WEATHER.

The term "angle of weather," used in connection with the following tables, means the angle made by the face of the sail with the plane of the wheel.

ARTIFICIAL WIND.

In conducting these experiments with windmills, it was necessary that results to be compared should be obtained in wind of uniform velocity. We therefore made use of artificial wind, obtained by carrying the wind wheels in a circle against still air on the end of a long sweep suspended beneath the roof trusses of a large room used for setting up tanks. The sweep was made to revolve horizontally around its vertical axis by means of gearing, pulleys, and belts connected with a line shaft driven by an 80-horsepower Reynolds–Corliss steam engine, which furnished the motive power for the works of the United States Wind Engine and Pump Company. The distance from axis of sweep to center of wind wheel was 14 feet, so that the velocity of wind against the wind wheel in miles per hour would be indicated very closely by the number of revolutions per minute made by the sweep. To attain absolute accuracy the length of sweep should have been 14.006 feet. Hence it was only necessary to note the number of turns per minute



PLAN AND ELEVATION OF DYNAMOMETER.

made by the sweep in order to know the velocity of wind in miles per hour with sufficient accuracy.

For counting the number of turns of the sweep a toothed wheel, containing 80 teeth, was used, which was made to revolve at the same rate as the sweep. Thus the fractions of a turn could be easily determined to within 0.0125, and we made a practice of setting down the fractional turns to within 0.00125, thus securing relative accuracy in determining the velocity of the wind to within 0.00125 of a mile per hour.

The face of the wind wheel was set at right angles to the direction of the wind. The frame supporting the shaft of the wind wheel was suspended about 3 feet below the sweep by four iron straps, presenting their thin edges to the wind, so that the action of the wind upon the wheel should be obstructed as little as possible by the sweep or otherwise. The motion of the sweep undoubtedly carried the air of the room with it to some extent, but not so as to produce a noticeable current.

DYNAMOMETER.

The ordinary Prony friction brake was used, with such modifications and additions as circumstances demanded.

The brake consisted of two pine blocks, clamped vertically upon a brass cylinder $5\frac{1}{4}$ inches in diameter, attached to the shaft of the wind wheel. But instead of using two bolts, with thumb nuts for adjusting the brake, one bolt was used as a hinge beneath the cylinder, and the adjustment was made by means of a cord passing across from one block to the other around small iron sheaves, which turned on common wood screws fastened into the tops of the two blocks, so that the pressure of the blocks against the cylinder corresponded to about sixteen times the tension of the cord.

The adjusting cord was carried back from the brake some distance in a direction parallel to the axis of the cylinder to a sheave fixed to the frame supporting the shaft of the wind wheel. From that point the cord was carried by means of sheaves, levers, etc., up through the hollow shaft supporting the sweep and finally fastened to one end of a lever. The other end of the lever was hinged and provided with a sliding weight, by means of which the tension of the cord could be adjusted from the station of observation while the sweep was in motion. The brake was provided with a horizontal graduated arm carrying a weight, which could be moved in or out to correspond to any desired load. Suitable stops were provided, allowing a limited motion of the brake and graduated arm, which could be conveniently watched from the station of observation, just beyond the reach of the sweep. The brake and graduated arm were balanced, as regards the action both of gravity and of centrifugal force, before applying the loads, which were balanced by the friction of the brake. The thrust of the rear end of the shaft of the wind wheel was sustained by a steel point.

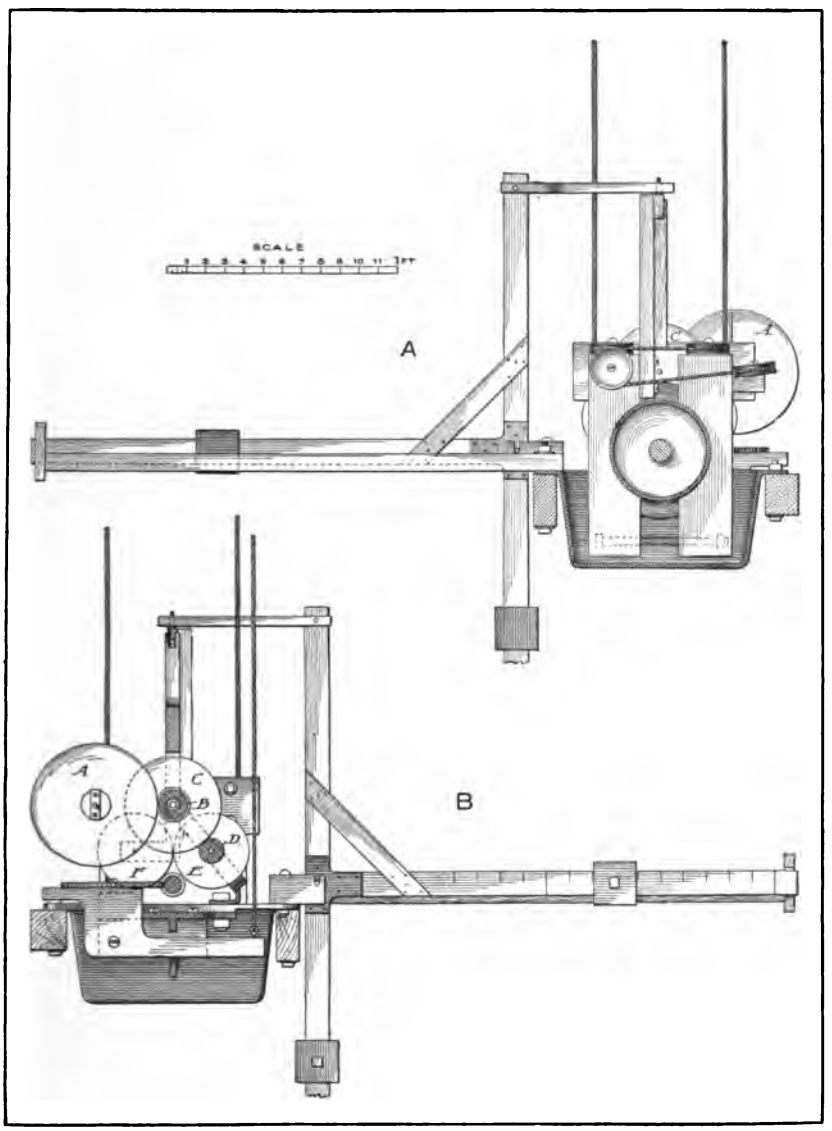
METHOD OF EXPERIMENT.

For noting the number of turns of the wind wheel, the rear end of the shaft was provided with a worm, with which a toothed wheel could be thrown in or out of contact at the pleasure of the operator from the station of observation. Each turn of the wind wheel would cause the toothed wheel to make 0.0125 of a revolution, as there were 80 teeth in the wheel, and the fractional turns could easily be estimated to within 0.1 of a revolution of the wind wheel. The weight on the graduated arm was always expressed in pounds and decimal parts at 1 foot from the center of shaft of the wind wheel. During use the brake was freely lubricated with machine oil.

For a trial load the weight on the graduated arm was set at some number, say 1 pound. Then the counter which was to record the speed of the wind wheel was set at 0, as was also the counter which was to record the velocity of the wind. The sweep having been set in motion, the speed of the wind wheel was checked by the brake, which was adjusted from the station of the observer by regulating the tension of the adjusting cord until the weight on the graduated arm was just lifted by the friction, and no more. As soon as the friction and weight were well balanced the counters which were to record the speed of the wheel and velocity of wind were thrown in by a single movement of a lever, and at the expiration of one minute they were both instantaneously thrown out. Then the sweep was stopped at the station of observation, the number of revolutions of the wind wheel recorded, and also the velocity of the wind.

To the load applied was added the friction of the journals, also expressed in pounds at 1 foot from the center of the shaft. This sum made the total load, which was multiplied by the number of turns of the wind wheel.

Then a second product was obtained in precisely the same manner with a greater load applied; and if greater than the first, a still greater load was applied and the corresponding product obtained. A succession of products were thus obtained corresponding to a succession of loads gradually increased until the products began to decrease on account of the diminishing speed of the wheel. The greatest product corresponded to the best load for the wheel, and the actual work performed by the wheel in each case could be obtained by multiplying the product by 6.2832 feet, equal to the circumference of the circle whose radius is 1 foot. In obtaining these products measurements were taken several times for each load and the total load was multiplied by the average turns of the wheel per minute. The average wind was also taken for record. The velocity of wind was supposed to be nearly uniform, but varied slightly with the speed of the engine, and the variation was sufficient to affect results considerably in some cases; hence the necessity of recording the velocity of the wind in each case. In comparing



END VIEWS OF DYNAMOMETER.

results some allowance also had to be made for differences in velocities of wind.

In testing the speed of the wheel unloaded the brake was removed, making the load nothing but the journal friction.

STARTING FORCES.

The determination of starting forces was attended with some difficulty. In the first place, it became necessary to define what should be considered the starting force of a wind wheel—whether it should be considered the greatest load under which the wheel would turn, or the greatest load which the wheel would balance without turning. It was also necessary to decide what motion of the wheel should be defined as turning. The wheel with a certain load would sometimes perform one revolution in ten or twenty minutes, if that could be called turning; between that and proper continuous turning there were many gradations. It was impracticable to decide when the wheel reached the lowest limit of speed which could properly be called turning. Therefore we have considered the starting force as the greatest load the wheel would balance without turning. Our method of determining starting forces was to clamp the brake so tightly on the cylinder that the wheel could not turn, but could lift the load applied such small distance as was allowed by the stops which limited the motion of the brake. The sweep was then set in motion and timed for one minute, during which time the load on the graduated arm was watched, its alternating upward and downward movements were noted, and judgment was exercised as to the balance between the load applied and the starting force of the wind wheel. The average velocity of wind during these tests was always recorded after March 13, 1883, but not always before that date.

In lifting the load the starting friction of the journals was also overcome by the wind wheel, but when the weight descended the load overcame the starting friction of journals in addition to the starting force of wind, and as the load almost constantly moved up and down when well balanced, nothing should be added to loads applied for friction in case of starting forces. Yet the friction has been added in the tables, the same as to other loads applied, in order to accommodate the statements at the head of columns for loads. On account of the starting friction being great and uncertain, and for other reasons, the starting forces recorded prior to March 13, 1883, are not so much to be relied upon as those recorded after that date; nor were the later tests for starting forces nearly so accurate as those for products.

JOURNAL FRICTION.

For journal friction previous to March 13, 1883, see description in connection with wind wheel No. 11, page 38. After the date above given the journal friction was greatly reduced by the use of large anti-

friction wheels in place of the front box, just behind the wind wheel and in front of cylinder, where the weight of the wind wheel and cylinder was mostly supported. In place of the rear box a small steel pin was inserted in the end of the shaft and turned in a brass box. The end thrust of the shaft, due to wind pressure and tension of the adjusting cord, was sustained by a steel point, as before.

As thus improved, one-half an ounce hung to a thread wound around the outside of wheel No. 37 overcame friction at very slow motion, and was almost if not quite equal to starting friction. The brake was removed during this test.

Let x = weight 12 inches from axis required to overcome friction.
30 inches = distance from axis to thread.
$\frac{1}{2}$ ounce = $\frac{1}{32}$ pound.

$$12\,x = \tfrac{30}{32}$$

$$x = 0.0785 = \text{friction at very slow motion or at starting.}$$

With brake and wind wheel removed 26.50 ounces hung by a thread wound around the forward end of shaft 0.7969 inch in diameter overcame friction at very slow motion and was almost equal to starting friction, and 24.25 ounces hung in the same way overcame friction at 50 turns per minute, and would not overcome friction when speed was much less. 0.8125 inch = diameter outside of thread, 0.4024 inch = radius to center of thread.

Friction at 50 turns per minute is to starting friction as 24.25 is to 26.50. Hence, $0.0785 \times \frac{24.25}{26.50} = 0.0714$ pound = journal friction at 50 turns per minute, with wind wheel on and brake removed. The weight of the brake would, of course, add a little to the friction, which we have uniformly called 0.1 in the tables, as explained on page 28, under the table.

The 0.3-pound friction added to loads applied prior to March 13, 1883, was friction at very slow motion and was undoubtedly much in excess of friction at speed of wheels corresponding to maximum products, as is evinced by the fact that notwithstanding the great reduction of starting friction the tables do not show for the same applied loads, or even unloaded, very much increase of speed of wheels after March 13, 1883, over speeds indicated previous to that date. If 0.1 pound had been added to applied loads previous to March 13, 1883, the products at maximum and for higher speeds of wheels would probably have been more nearly correct. It was this uncertainty and ignorance regarding friction at different speeds that led us to reduce as much as possible this source of error. However, the error thus arising does not greatly affect comparative values of products recorded prior to March 13, 1883, although products affected by allowance of 0.3 pound for friction should not, unless corrected, be compared with products recorded after above date.

COMPARATIVE STANDARD WHEEL.

In the earlier stages of these experiments we acted on the supposition that only such variations in the state of the atmosphere as were indicated by the barometer and thermometer should affect the work performed by a wheel tested at different times in wind of the same velocity. But later we were convinced that the readings of the barometer and thermometer would not always account for variations in products given by the same wheel on different days. We were also convinced of the uselessness of speculating as to, or trying to understand and forestall, all the causes that might combine to affect results. Therefore we adopted the practice of comparing the maximum product of each wheel tested with the maximum product of wheel No. 2, obtained in close proximity as to time and under similar conditions in all respects. This could be done with a good deal of certainty, and no further trouble was experienced on account of contradictory results. After the best loads had been ascertained by trial, comparative tests were made by trying first one wheel and then the other in succession until a considerable number of measurements had been taken. Then as many measurements as possible, giving the same average velocity of wind for both wheels, were selected from each set of experiments.

In this way the product obtained was usually the average of 8 to 10 measurements of each wheel made under the same conditions of time, wind, weather, and whatever else might affect the results. The product of No. 2 was thus used as a standard of measure, and the ratio of products indicated the relative value of the wheel compared.

For further particulars consult tables of experiments of later date than March 13, 1883.

Results of experiments performed in March and May, 1883, with wheel No. 2.

Velocity of wind per hour.	Load applied + 0.1 for friction.	Turns of wheel per minute.	Product at maximum.	Thermometer.	Date.
Miles.	*Pounds.*			°F.	1883.
6.437	0.1	43.78	.....	62	May 14
6.371	1.1	23.90	26.290	54	May 14
6.381	2.4	0	.....	62	May 14
8.417	.1	59.05	.....	53	Mar. 14
8.403	1.9	32.875	62.463	50	Mar. 14
8.405	4.2	0	.....	53	Mar. 14
10.898	.1	77.85	.....	46	May 21
11.041	3.3	41.06	135.498	60	May 17
10.976	6.9	0	.....	46	May 21

Previous to making the above experiments, March 13, 1883, the dynamometer was improved by the addition of an automatic brake adjuster

and antifriction wheels, which reduced starting friction from about 0.3 to about 0.08 pound, and made journal friction at 50 turns per minute about 0.071 pound. In the table friction was called 0.1 pound for convenience, as the absolute friction in each case could not easily be obtained, and the error does not materially affect comparative results. (See pages 25 and 26 for "Journal friction.")

Average products of wheel No. 2, which was used as a standard for comparison, were obtained by selecting from numerous tests several numbers—generally 8 to 10—which corresponded to wind of the same average velocity as wind for wheels compared in each case; the difference of averages in no case exceeded 0.001 mile per hour in the table on page 47.

Measurements for maximum products of two wheels compared were always taken as far as possible under the same conditions of wind, temperature, barometer, weather, time, etc.

RESULTS OF ORIGINAL TESTS.

TABLES AND DESCRIPTIONS OF WIND WHEELS.

WHEEL NO. 1.—*Results of experiments.*

Velocity of wind per hour.	Load applied +0.3 for friction.	Turns of wheel per minute.	Product.
Miles.	*Pounds.*		
8.427	0.3	59.08	17.724
8.431	1.2	42.60	51.120
8.385	1.4	39.90	55.860
8.412	1.6	35.69	57.104
8.452	1.8	31.69	57.042
8.432	2.0	28.02	56.040
.....	2.85	0	0

Experiments made June 1 and 2, 1882.
Load expressed in pounds applied 1 foot from center of wheel.
Circumference of circle whose radius is 1 foot, 6.2832 feet.
Work per minute at the maximum, $57.104 \times 6.283 = 358.784$ foot-pounds
Diameter of wheel, 5 feet.
Number of slats or sails, 30.
Length of slats, 18 inches.
Width of slat at outer end, 3.56 inches.
Width of slat at inner end, 1.344 inches.
Total area of slats or sails, 9.19 square feet.
Angle of weather, 35 degrees.
Portion of available annular space filled by sails, 0.5.
The spaces between are equal to the spaces occupied by the slats. This wheel is the same as No. 2 with one-half the slats omitted.
Slats, plain surfaces, made of white pine three-sixteenths of an inch thick, with forward edges trimmed to an edge.

WHEEL No. 2.—*Results of experiments.*

Velocity of wind per hour.	Load applied + 0.3 for friction.	Turns of wheel per minute.	Product.	Thermometer.	Date.
Miles.	*Pounds.*			° *F.*	1882.
8.411	0.3	57.95	17.385	69	.....
8.381	0.9	49.00	44.100	.....	.....
8.451	1.05	47.00	49.350	.....	.....
8.435	1.3	43.08	56.004	77	June 7
8.445	1.5	40.80	61.200	73	June 7
8.412	1.7	37.30	63.410	70	June 7
8.460	1.8	35.85	64.530	78	.....
8.436	1.9	34.89	66.291	72	June 8
8.429	2.0	33.43	66.860	78	.....
8.443	2.1	31.33	65.793	69	June 8
8.421	2.3	27.60	63.480	73	June 8
8.446	2.5	24.48	61.200	75	June 8
8.416	2.7	21.70	58.590	76	June 8
8.398	2.9	20.00	58.000	.....	.....
8.338	3.1	15.80	48.980	.....	.....
.....	3.81	0	0	.....	June 9

Total area of slat sails 18.380 square feet.

Angle of weather, 35 degrees.

The same as No. 1, with double the number of slats—that is, the projections of the slats upon the plane of the wheel equaled the entire available annular area. An area as shown in fig. 8 at each of the six arms constituted the space not available. Slats held in place by 12 straight notched pieces extending from arm to arm the same as in No. 1.

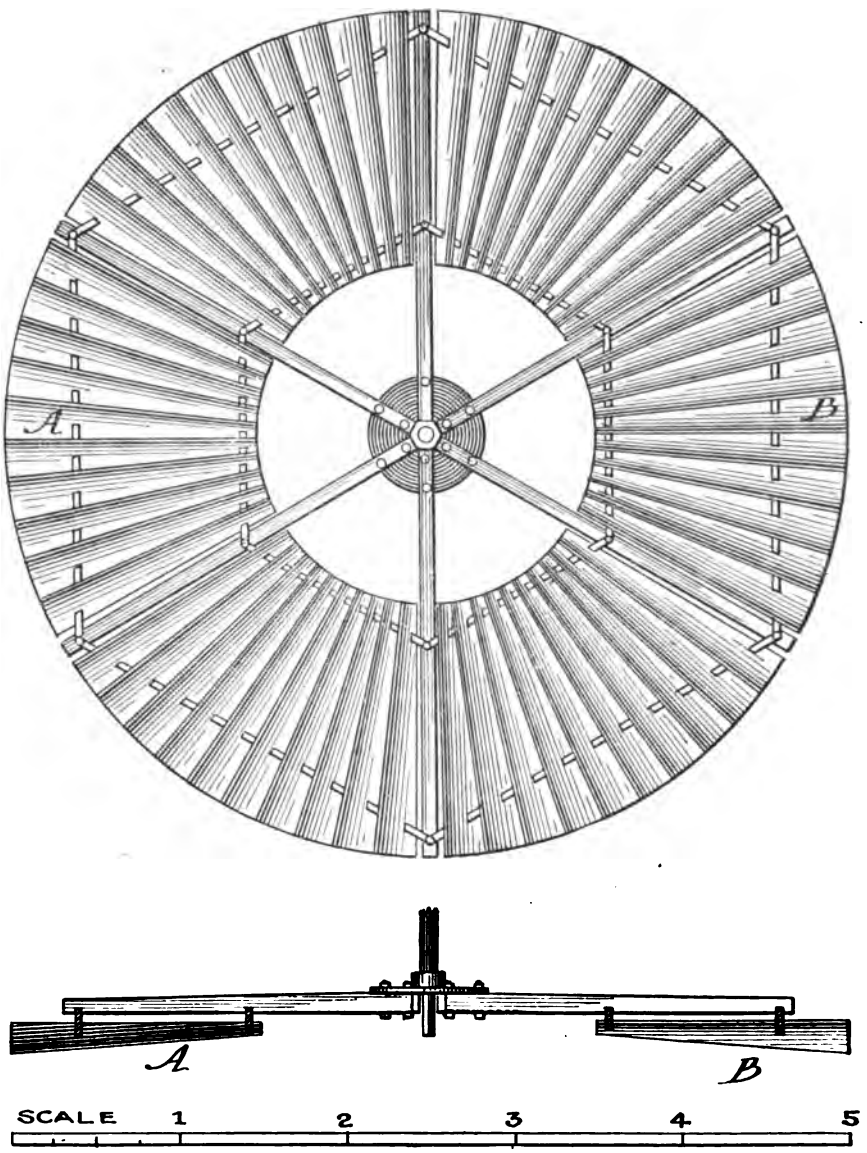


FIG. 7.—Elevation and section of wheel No. 2. (Sail area, 18.380 square feet; efficiency, 0.154.)

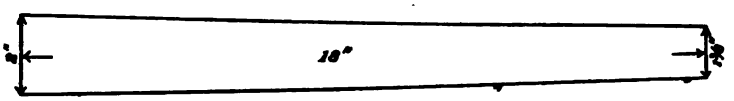


FIG. 8.—Outline of area not available.

WHEEL NO. 3.—*Results of experiments.*

Velocity of wind per hour.	Loads applied + 0.3 for friction.	Turns of wheel per minute.	Product.	Thermometer.	Date.
Miles.	*Pounds.*			° *F.*	1882.
8.476	0.3	90.48	27.144	68	June 22
8.435	.95	69.40	65.930	68	June 22
8.441	1.05	64.90	68.145	68	June 21
8.428	1.1	62.15	68.365	88	June 22
8.447	1.2	59.65	71.580	69	June 19
8.436	1.3	55.36	71.968	83	June 22
8.402	1.4	51.10	71.540	69	June 21
8.423	1.5	47.48	71.220	74	June 19 June 22
8.441	1.7	41.00	69.700	71	June 22
8.404	1.9	32.00	60.800	71	June 22
.....	2.4	0	0	.....	June 22

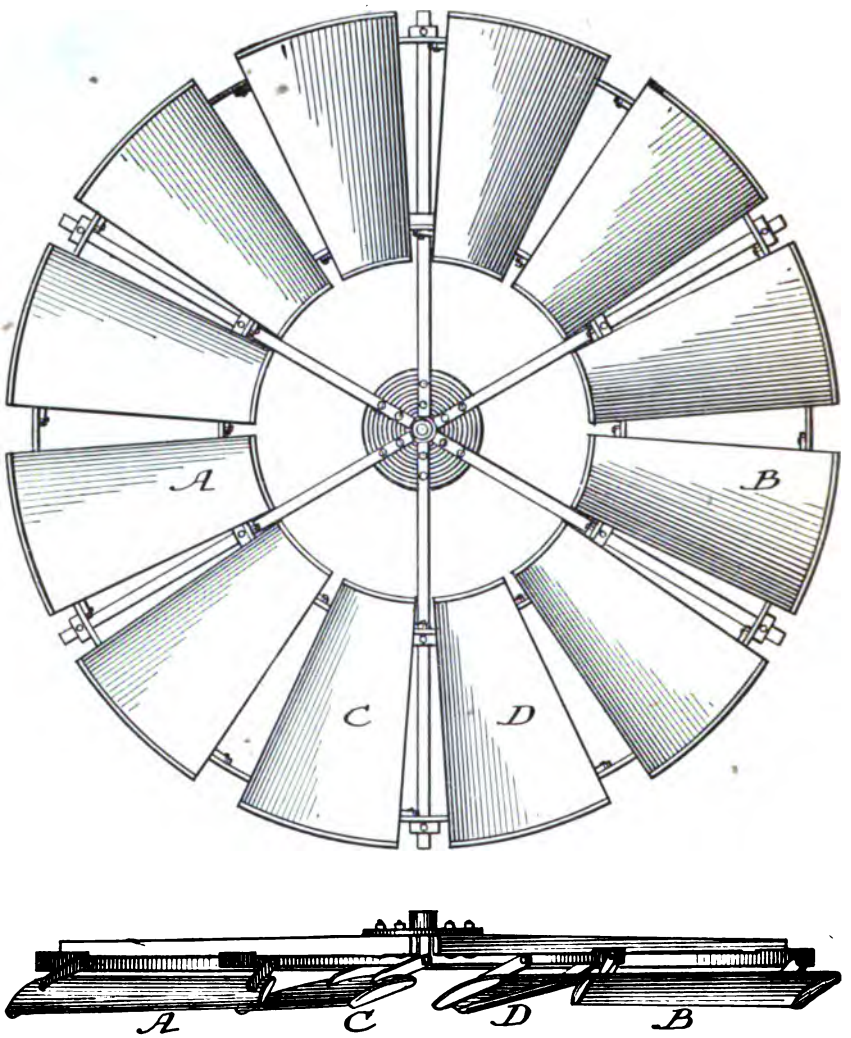


FIG. 9.—Elevation and section of wheel No. 3. (Sail area, 13.590 square feet; efficiency, 0.161.)

Diameter of wheel, 5 feet.

Number of sails, 12.

Sails of lineal dimensions as shown in figs. 10 and 11, made of white-pine boards three-sixteenths of an inch thick and fastened by hinges near each end to 12 pine bands bent to arcs of circle and secured to the 6 arms.

Total sail surface, 13.59 square feet.

Sails concave toward the wind.

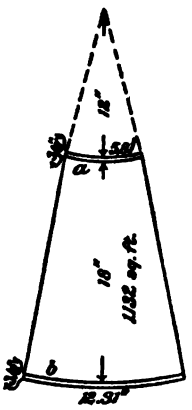


FIG. 10.—Dimensions of sails of wheel No. 3. 18 inches is the extreme length of sail.

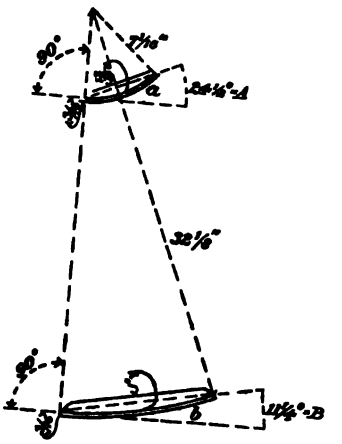


FIG. 11.—Angles of weather of sails of wheel No. 3. *A*, Angle of weather at inner ends of sails; *B*, Angle of weather at outer ends of sails.

WHEEL NO. 4.—*Results of experiments.*

Velocity of wind per hour.	Load applied + 0.3 for friction.	Turns of wheel per minute.	Product.	Thermometer.	Date.
Miles.	*Pounds.*			° *F.*	1882.
8.354	0.3	89.43	26.829	76	June 29
8.372	0.9	74.54	67.086	76	June 29
8.375	1.1	70.03	77.033	76	June 29
8.324	1.3	62.75	81.575	68	June 29
8.461	1.5	60.72	91.080	73	June 28
8.467	1.7	55.93	95.081	73	June 28
8.465	1.9	48.75	92.625	73	June 28
8.366	2.1	42.78	89.838	68	June 29
8.386	2.3	38.50	88.550	68	June 29
8.369	2.5	29.13	72.825	68	June 29
.....	3.3	0	0	.....	June 29

Wheel the same as No. 3, except that the inclination of the sails was changed, making the angle of weather 20 degrees at outer ends of sails and 30 degrees at inner ends of sails.

WHEEL NO. 5.—*Results of experiments.* (*a*)

Velocity of wind per hour.	Loads applied +0.3 for friction.	Turns of wheel per minute.	Product.	Thermometer.	Date.
Miles.	*Pounds.*			°*F.*	1882.
8.444	0.3	86.78	26.034	74	July 12
8.499	0.9	73.56	66.204	74	July 12
8.479	1.1	68.72	75.592	74	July 12
8.493	1.3	64.18	83.434	71	July 5
8.419	1.5	57.98	86.970	71	July 5
8.422	1.7	53.86	91.562	71	July 5
8.468	1.9	50.83	96.577	71	July 5
8.465	2.1	46.10	96.810	74	July 5
8.456	2.3	41.60	95.680	74	July 5
8.414	2.5	33.86	84.650	63	July 6
8.424	2.7	27.70	74.790	63	July 12
8.440	2.9	19.62	56.898	63	July 12
.....	3.7	0	0	.....	July 5
8.491	1.9	51.88	98.572	71	.....

a See wheel No. 44, p. 57.

Wheel the same as No. 3, except that the inclination of the sails was changed, making the angle of weather 22.5 degrees at outer ends of sails and 32.5 degrees at inner ends of sails.

WHEEL NO. 6.—*Results of experiments.*

Velocity of wind per hour.	Load applied + 0.3 for friction.	Turns of wheel per minute.	Product.	Thermometer.	Date.
Miles.	*Pounds.*			°*F.*	1882.
8.373	0.3	69.03	20.709	32	Dec. 9
8.355	1.5	47.30	70.950	34	Dec. 9
8.348	1.7	44.00	74.800	34	Dec. 9
8.405	1.8	42.10	75.780	35	Dec. 9
8.317	1.9	38.28	72.732	35	Dec. 9
a 8.368	1.3	50.83	66.079	38	Dec. 9
.....	3.4	0	0	33	Dec. 8

a When reversed, so as to present its back side to the wind.

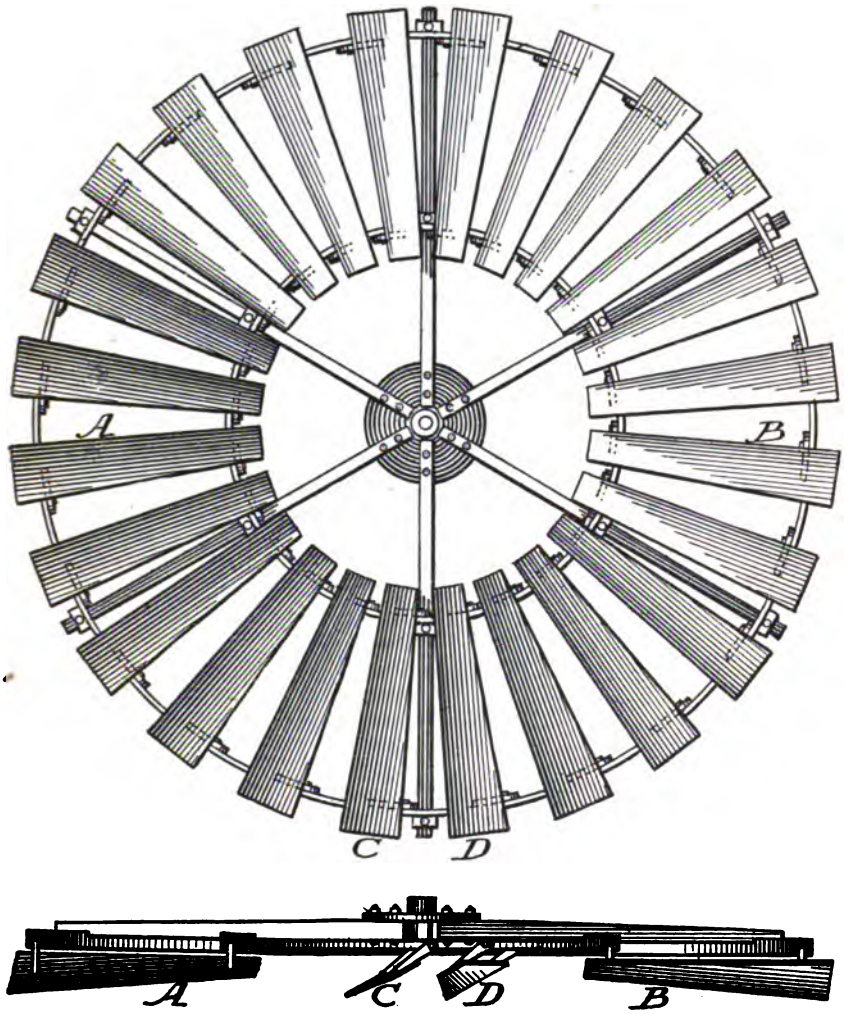


FIG. 12.—Elevation and section of wheel No. 6. (Sail area, 10.688 square feet; efficiency, 0.163.)

Diameter of wheel, 5 feet.

Arms and bands the same as in wheel No. 3.

Number of sails, 24. Sails of lineal dimensions as in fig. 13; made of white-pine boards three-sixteenths of an inch thick, and hinged to the bands as in No. 3.

Sails plain, with forward edges trimmed to an edge.

Total sail surface, 10.688 square feet.

Angle of weather, 30 degrees.

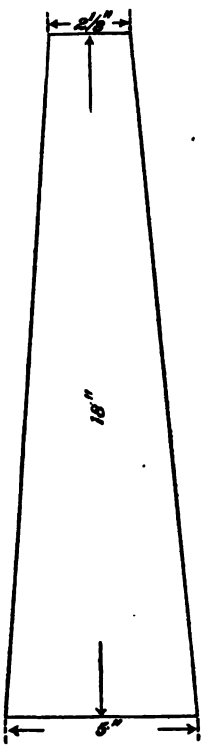


FIG. 13.—Dimensions of sails of wheel No. 6.

WHEEL NO. 7.—*Results of experiments.*

Velocity of wind per hour.	Loads applied + 0.3 for friction.	Turns of wheel per minute.	Product.	Thermometer.	Date.
Miles.	*Pounds.*			°*F.*	1882.
8.361	0.3	73.60	22.080	42	Dec. 12
8.380	1.3	52.50	68.250	39	Dec. 12
8.416	1.5	47.40	71.100	40	Dec. 11
8.359	1.7	40.74	69.258	40	Dec. 12
.....	2.8	0	0	42	Dec. 12

Wheel the same as No. 6, except that the inclination of the sails was changed, making the angle of weather 25 degrees.

WHEEL NO. 8.—*Results of experiments.*

Velocity of wind per hour.	Loads applied + 0.3 for friction.	Turns of wheel per minute.	Product.	Thermometer.
Miles.	*Pounds.*			°*F.*
8.333	0.3	62.67	18.801	.....
8.344	1.3	46.83	60.879	48
8.403	1.5	44.23	66.345	48
8.375	1.7	40.23	68.391	39
8.366	1.9	36.84	69.996	41
8.368	2.1	32.80	68.880	47
8.354	2.3	27.70	63.710	47
.....	3.55	0	0	.....

Experiments made December 13, 1882.

Wheel the same as No 6, except that the inclination of the sails was changed, making the angle of weather 35 degrees.

WHEEL NO. 9—*Results of experiments.*

Velocity of wind per hour.	Loads applied + 0.3 for friction.	Turns of wheel per minute.	Product.	Thermometer.
Miles.	*Pounds.*			°*F.*
8.374	0.3	66.40	19.920	43
8.361	1.3	49.73	64.649	38
8.375	1.5	47.15	70.725	39
8.350	1.7	42.30	71.910	40
8.364	1.9	38.20	72.580	40
8.344	2.1	34.58	72.618	42
8.323	2.3	30.70	70.610	42
.....	3.4	0	0	.....

Experiments made December 14, 1882.

Wheel the same as No. 6, except that the inclination of the sails was changed, making the angle of weather 32.5 degrees.

WHEEL NO. 10.—*Results of experiments.*

Velocity of wind per hour.	Loads applied + 0.3 for friction.	Turns of wheel per minute.	Product.	Thermometer.	Date.
Miles.	*Pounds.*			°*F.*	1882.
8.347	0.3	72.23	21.690	34	Dec. 15
8.336	1.1	54.77	60.247	45	Dec. 14
8.329	1.3	53.30	69.290	45	Dec. 14
8.345	1.5	48.70	73.050	33	Dec. 15
8.358	1.7	43.78	74.426	34	.....
8.338	1.9	39.33	74.727	35	.....
8.351	2.1	35.06	73.626	39	.....
.....	3.25	0	0	.....	.....

Wheel the same as No. 6, except that the inclination of the sails was changed, making the angle of weather 27.5 degrees.

WHEEL NO. 11.—*Results of experiments.*

Velocity of wind per hour.	Loads applied + 0.3 for friction.	Turns of wheel per minute.	Product.	Thermometer.
Miles.	*Pounds.*			°*F.*
8.415	0.3	77.60	23.280	41
8.353	1.3	51.64	67.132	39
8.391	1.5	45.46	68.190	40
8.401	1.7	39.52	67.184	40
8.410	1.9	*a* 33.14	62.966	41
.....	2.1	(*b*)	.....	.....
.....	2.3	0	0	.....

a Started slowly and with difficulty, though well balanced. Once needed help to start.
b Ran slowly two or three minutes and stopped.

Experiments made December 18, 1882.

Wheel the same as No. 6, except that the inclination of the sails was changed, making the angle of weather 20 degrees.

A journal friction test made with wheel No. 11 by hanging a 1¼-ounce weight by a thread wound around the outside of the wheel showed that this weight did not overcome starting friction, but was sufficient to accelerate motion after the wheel was started at moderate speed.

Let x = journal friction, at 1 foot (12 inches) from axis.

30 inches = distance of 1¼-ounce weight from axis.

$1.75 \times 30 = 12\,x$.

$x = 4.375$ ounces = 0.2734 pound = friction of journals at moderate speed.

The journal friction diminishes somewhat with the increase of speed, although authorities give the same coefficient of friction at all speeds. Some variation in journal friction is also due to difference in weights of wheels and in lubrication; and as the above test was made with the brake removed, we have considered it approximately correct to call journal friction = 0.3 pound in all cases. See, however, later conclusions.

WHEEL No. 12.—*Results of experiments.*

Velocity of wind per hour.	Load applied + 0.3 for friction.	Turns of wheel per minute.	Product.	Thermometer.
Miles.	*Pounds.*			° *F.*
8.405	0.3	75.60	22.680	44
8.385	.95	56.18	53.371	40
8.376	1.1	50.78	55.858	40
8.341	1.3	*a* 43.88	57.044	41
8.376	1.5	*b* 35.42	53.130	42
.....	1.6	(*c*)	.....	.....
.....	1.7	0	0	.....

a Started slowly.

b Needed assistance to start in every instance, though without assistance it would barely move, at the rate, perhaps, of one turn in ten minutes.

c Ran three minutes and stopped, after having been started at moderate speed.

Experiments made December 19, 1882.

Wheel the same as No. 6, except that the inclination of the sails was changed, making the angle of weather 15 degrees.

WHEEL No. 13.—*Results of experiments.*

Velocity of wind per hour.	Load applied + 0.3 for friction.	Turns of wheel per minute.	Product.	Thermometer.	Date.
Miles.	*Pounds.*			° *F.*	1882.
8.369	0.3	56.33	16.899	45	Dec. 20
8.377	1.7	37.13	63.121	45	Dec. 19
8.353	1.9	34.10	64.790	43	Dec. 20
8.352	2.1	31.30	65.730	41	Dec. 20
8.407	2.3	28.70	66.010	42	Dec. 20
8.375	2.5	25.38	63.450	42	Dec. 20
8.328	2.7	20.63	55.701	44	Dec. 20
8.351	2.9	17.25	50.025	46	Dec. 20
.....	3.1	(*a*)	.....	.....	Dec. 20
.....	3.2	(*b*)	.....	.....	Dec. 20
.....	3.7	0	0	.....	Dec. 20

a Ran very slowly after starting, and stopped several times.

b Stopped and started occasionally.

Wheel the same as No. 6, except that the inclination of the sails was changed, making the angle of weather 40 degrees.

WHEEL NO. 14.—*Results of experiments.*

Velocity of wind per hour.	Load applied + 0.3 for friction.	Turns of wheel per minute.	Product.	Thermometer.
Miles.	*Pounds.*			° *F.*
8.327	0.3	48.60	14.580	47
8.335	1.5	33.60	50.400	46
8.375	1.7	32.68	55.556	46
8.393	1.9	29.88	56.772	47
8.336	2.1	26.95	56.595	46
8.364	2.3	24.72	56.856	46
8.427	2.5	21.82	54.550	46
8.381	2.7	17.98	48.546	46
8.409	2.9	15.10	43.790	46
8.349	3.1	12.47	38.657	46
.....	3.3	(*a*)	.....	.....
.....	3.8	0	0	.....

a Ran a minute or two, stopped, and afterwards started slightly.

Experiments made December 21, 1882.

Wheel the same as No. 6, except that the inclination of the sails was changed, making the angle of weather 45 degrees.

WHEEL NO. 15.—*Results of experiments.*

Velocity of wind per hour.	Load applied +0.3 for friction.	Turns of wheel per minute.	Product.	Thermometer.
Miles.	*Pounds.*			° *F.*
8.444	0.3	46.84	14.052	30
8.402	1.7	29.36	49.912	28
8.429	1.9	27.40	52.600	30
8.479	2.1	25.30	53.130	31
8.457	2.3	22.92	52.716	33
8.443	2.5	20.17	50.425	32
8.440	2.7	17.71	47.817	33
8.438	3.1	10.20	31.620	35
.....	3.3	(*a*)	.....	30
.....	3.5	(*b*)	.....	30
8.406	3.95	0	0	35

a Turned very slowly and irregularly. *b* Barely moved.

Experiments made January 5 and 6, 1883.

Wheel the same as No. 6, except that the inclination of the sails was changed, making the angle of weather 47.5 degrees.

WHEEL No. 16.—*Results of experiments.*

Velocity of wind per hour.	Load applied + 0.3 for friction.	Turns of wheel per minute.	Product.	Thermometer.
Miles.	*Pounds.*			° *F.*
8.443	0.3	42.40	12.720	32
8.444	1.7	27.75	47.175	32
8.440	1.9	24.92	47.348	30
8.385	2.1	23.27	48.867	30.5
8.447	2.3	20.67	47.514	38
8.419	2.5	18.45	46.125	37
8.505	2.7	16.23	43.821	37
8.426	2.9	*a* 12.33	35.757	37
8.484	3.1	(*b*)	.....	36
.....	3.3	(*c*)	.....	36
8.257	3.55	0	0	35
8.426	3.9	0	0	36

a Almost needed help to start, and once stopped within one minute.
b Stopped after running one minute.
c Stopped after running very slowly a short time.

Experiments made January 6 and 8, 1883.

Wheel the same as No. 6, except that the inclination of the sails was changed, making the angle of weather 50 degrees.

Comparative results with plain sails.

A	B	C	D	E	F	G	H	I
No. of wheel.	Angle of weather.	Velocity of wind per hour at maximum.	Greatest load.	Load at maximum.	Turns of wheel per minute at maximum.	Turns of wheel per minute unloaded.	Products at maximum work, E × F.	Total sail surface.
	°	*Miles.*	*Pounds.*	*Pounds.*				*Sq. ft.*
1	35	8.412	2.85	1.6	35.69	59.08	57.104	9.190
2	35	8.429	3.81	2.0	33.43	57.95	66.860	18.380
12	15	8.341	1.7	1.3	43.88	75.60	57.044	10.688
11	20	8.391	2.3	1.5	45.46	77.60	68.190	10.688
7	25	8.416	2.8	1.5	47.40	73.60	71.100	10.688
10	27.5	8.358	3.25	1.7	43.78	72.23	74.426	10.688
6	30	8.348	3.4	1.7	44.00	69.03	74.800	10.688
9	32.5	8.364	3.4	1.9	38.20	66.40	72.580	10.688
8	35	8.366	3.55	1.9	36.84	62.67	69.996	10.688
13	40	8.352	3.7	2.1	31.30	56.33	65.730	10.688
14	45	8.336	3.8	2.1	26.95	48.60	56.595	10.688
15	47.5	8.479	3.95	2.1	25.30	46.84	53.130	10.688
16	50	8.385	3.9	2.1	23.27	42.40	48.867	10.688

No. 2 modeled after Halliday 10-foot mill, and contained 60 sails 18 inches long and 3.56 inches wide at outer end.

No. 1 contained 30 sails 18 inches long and 3.56 inches wide at outer end.

Nos. 6–16 contained 24 sails 18 inches long and 5 inches wide at outer end.

If the separate tables are consulted, it will be found that in making out the comparative table, we have not taken the highest products for wheels Nos. 6, 9, 10, 13, and 14, in column H. As the angle of weather increases from 15 degrees to 47.5 degrees, the loads at maximum should obviously increase or at least should not decrease in any case within those limits. This law would apparently have been violated if we had taken the highest products in the above-mentioned cases. So, in Nos. 6, 9, 10, 13, and 14, we have taken the loads and products immediately preceding those corresponding to maximum. By so doing we made column E appear consistent with the law of increasing loads without materially changing the values of products in column H. For it will be noted that in no case does the product we have set down in column H fall short of the highest we might have taken by so much as unity.

The majority of the slight discrepancies in column H are clearly accounted for by the variation in wind as shown in column C. But in Nos. 9 and 10 there was evidently a slight fault in adjusting the friction of the brake to the load applied. Slight errors of this nature are unavoidable, although they may be reduced to a minimum by the exercise of care and repeated trials. (See page 27.)

In the foregoing experiments seldom less than six measurements were made for the determination of each product and sometimes the unsteadiness of the wind required many more trials for the determination of a product. The variations in wind, though not great, sometimes made a difference of one or two turns of the wheel per minute. The indicator which registered the number of turns of the wheel was not originally intended to indicate fractions of a turn, although the fractional turns were actually set down by estimation to within one-tenth of a turn. But the indicator could not be counted on as absolutely correct to within less than half a turn, so that an error of half a turn too much or too little might sometimes account for a variation of one turn of the wheel. Since, however, the indicator was just as liable to make the fractional error one way as the other, the errors in average results would be probably diminished in proportion to the number of tests from which the averages were deduced.

The indicator consisted of a toothed wheel which was thrown in contact with a worm on the shaft of the wheel, and the teeth were liable to strike the worm so as to accelerate or retard the indicator to the extent of half the pitch of the teeth or less.

An examination of the several tables shows that there are generally three or four consecutive products corresponding to different loads, none of which vary much from the greatest product, and when the two highest products are nearly identical, as often happens, it requires but a very slight error in any one of two or three chances for variation to make the highest product correspond to either of two consecutive loads.

WHEEL NO. 17.—*Results of experiments.*

Velocity of wind per hour.	Load applied + 0.3 for friction	Turns of wheel per minute.	Product.	Thermometer.
Miles.	*Pounds.*			° *F*
8.392	0.3	73.90	22.170	32
8.379	1.3	52.62	68.406	30
8.363	1.5	46.55	69.825	30
8.390	1.7	42.80	72.760	31
8.408	1.9	38.70	73.530	31
8.373	2.1	33.30	69.930	31
8.400	3.05	0	0	32
a 8.391	.3	79.83	23.949	32
a 8.380	1.3	54.15	70.395	32
a 8.374	1.5	47.60	71.400	31
a 8.361	1.7	40.70	69.190	32

a Reversed.

Experiments made January 10 and 11, 1883.

Wheel the same as No. 6, except that the sails were twisted, making the angle of weather 25 degrees at outer extremities of sails and 35 degrees at inner extremities of sails.

The twisting made the sails somewhat convex on the front side and concave on the reversed side.

WHEEL NO. 18.—*Results of experiments.* (*a*)

Velocity of wind per hour.	Load applied + 0.3 for friction.	Turns of wheel per minute.	Product.	Thermometer.
Miles.	*Pounds.*			° *F.*
8.430	0.3	75.58	22.674	37
8.370	1.3	53.48	69.524	37
8.362	1.5	50.64	75.960	38
8.386	1.7	48.08	81.736	38
8.397	1.9	43.31	82.289	39
8.393	2.1	39.42	82.782	40
8.357	2.3	33.65	77.395	39
8.368	2.5	*b* 28.31	70.775	40
8.419	2.7	*c* 21.83	58.941	37
8.440	3.4	0	0	38

a See table on p. 47.

b Started slowly.

c Started very slowly—almost needed help.

Experiments made January 13 and 17, 1883.

Wheel contained 24 sails of lineal dimensions as shown in fig. 14, made of white-pine boards three-sixteenths inch thick, beveled on forward edges, and hinged to the bands the same as in wheel No. 6.

Total area of sail surface, 12.937 square feet.

Angle of weather, 25 degrees.

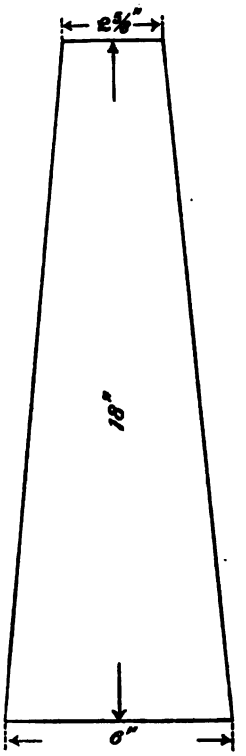


FIG. 14.—Dimensions of sails of wheel No. 18.

WHEEL NO. 19.—*Results of experiments.* (*a*)

Velocity of wind per hour.	Load applied +0.3 for friction.	Turns of wheel per minute.	Product.	Thermometer.
Miles.	*Pounds.*			° *F.*
8.375	0.3	72.26	21.678	33
8.375	1.3	53.78	69.914	34
8.466	1.5	50.32	75.480	28
8.475	1.7	47.17	80.189	28
8.379	1.9	44.48	84.512	29
8.422	2.1	42.10	88.410	30
8.439	2.3	38.20	87.860	31
8.400	2.5	32.95	82.375	31
8.397	2.7	26.98	72.846	31
8.392	2.9	22.03	63.887	32
8.370	3.1	*b* 16.03	49.693	32
8.329	3.6	0	0	32

a See table on page 47. *b* Needed assistance to start.

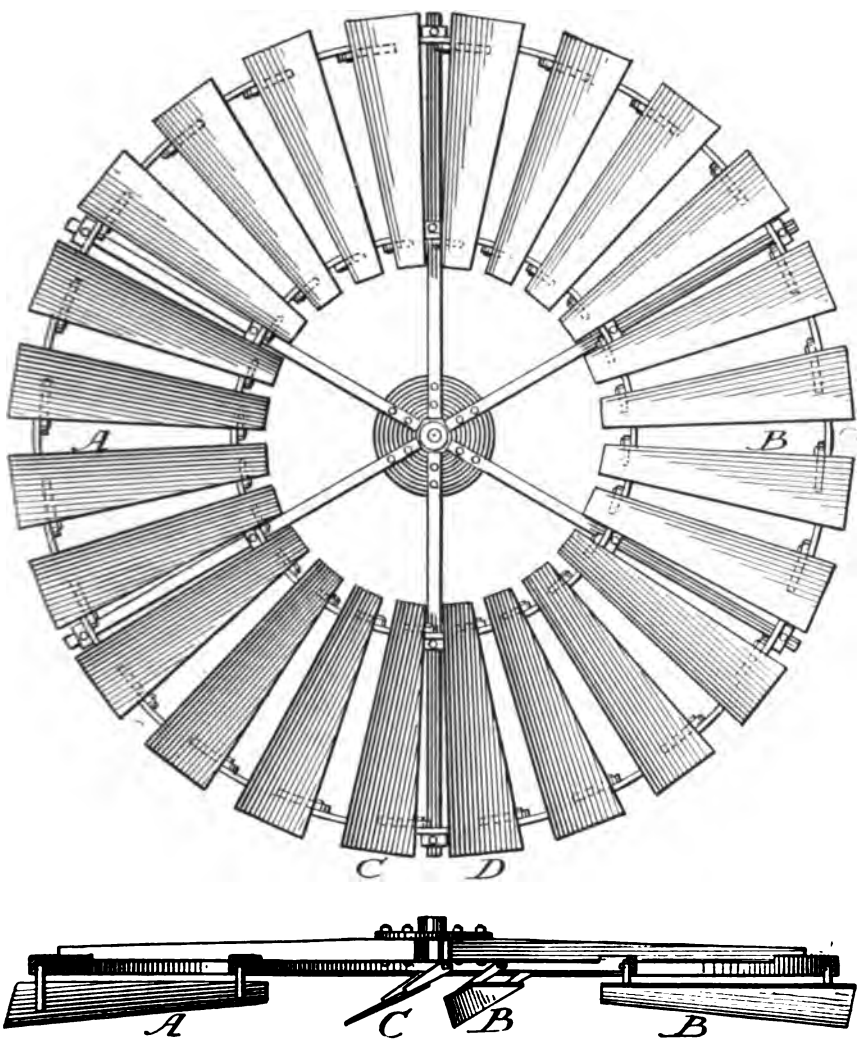


FIG. 15.—Elevation and section of wheel No. 19. (Sail area, 12.937 square feet; efficiency, 0.185).

Experiments made January 18, 1883.

Wheel the same as No. 18, except that the inclination of the sails was changed, making the angle of weather 27.5 degrees.

WHEEL NO. 23.—*Results of experiments.*

Velocity of wind per hour.	Load applied + 0.3 for friction.	Turns of wheel per minute.	Product.	Thermometer.
Miles.	*Pounds.*			° *F.*
8.422	0.3	73.46	22.038	34
8.420	1.3	55.60	72.280	30
8.428	1.5	50.83	76.245	30
8.486	1.7	47.64	80.988	30
8.444	1.9	43.21	82.099	30
8.400	2.1	38.14	80.094	30
8.402	2.3	34.30	78.890	31
8.382	2.5	30.12	75.300	31
8.434	*a* 2.7	24.23	65.421	32
8.399	3.55	0	0	32

a Needed assistance to start.

Experiments made January 25, 1883.

Wheel the same as No. 18, except that the angle of weather was 25 degrees at outer ends of sails and 30 degrees at inner ends.

COMPARISON OF SEVERAL WHEELS.

WHEELS NOS. 2 AND 50.—*Results of experiments.*

No. of wheel.	Velocity of wind per hour.	Load applied +0.1 for friction.	Turns of wheel per minute.	Date.
	Miles.	*Pounds.*		1883.
2	11.022	0.1	77.75	July 2
2	11.054	3.3	38.48	July 2
2	10.926	6.8—	0	July 2
50	11.093	0.1	77.45	July 2
50	11.054	3.3	36.36	July 2
50	10.981	6.6	0	July 2

Wheel No. 50 was No. 2 with the center of wheel filled in by a cone whose base was 24 inches in diameter and whose slant height was 18 inches. Base of cone rested against the front of arms of wheel. Cone made of stiff paper, supported by light wooden frame.

WHEELS NOS. 18 TO 22.—*Results of experiments.*

No. of wheel.	Angle of weather.	Velocity of wind per hour.	Load applied +0.1 for friction.	Turns of wheel per minute.	Product at maximum.	Product of No. 2 at maximum.	Ratio of products.	Date.
	°	*Miles.*	*Pounds.*					1883.
18	25	8.516	0.1	77.13	.....	.....	.....	Apr. 10
18	25	8.485	1.5	46.20	69.300	58.083—	1.193	Apr. 10
18	25	8.444	3	0	.....	.....	.....	Apr. 10
19	27.5	8.471	0.1	74.94	.....	.....	.....	Apr. 12
19	27.5	8.500	1.9	39.57	75.185	62.719+	1.204	Apr. 11
19	27.5	8.455	3.3	0	.....	.....	.....	Apr. 11
20	30	8.464	0.1	70.78	.....	.....	.....	Apr. 14
20	30	8.486	1.9	39.87	75.753	62.966—	1.203	Apr. 12
20	30	8.475	3.55	0	.....	.....	.....	Apr. 14
21	32.5	8.478	0.1	67.97	.....	.....	.....	Apr. 16
21	32.5	8.463	1.9	38.72	73.568	*a*62.225=	1.182	Apr. 16
21	32.5	8.400	3.7	0	.....	.....	.....	Apr. 16
22	35	8.498	0.1	64.20	.....	.....	.....	Apr. 17
22	35	8.461	2.1	31.96	67.166	58.957—	1.138	Apr. 17
22	35	8.504	3.9	0	.....	.....	.....	Apr. 17

a The sign = indicates that the number affected needs no correction.

These wheels differed from each other only in angles of weather.

WHEELS NOS. 24 TO 28.—*Results of experiments.*

No. of wheel.	Angle of weather.	Velocity of wind per hour.	Load applied +0.1 for friction.	Turns of wheel per minute.	Product at maximum.	Product of No. 2 at maximum.	Ratio of products.	Date.
	°	*Miles.*	*Pounds.*					1883.
26	25	8.455	0.1	75.38	.....	.....	.....	Apr. 9
26	25	8.434	1.7	43.74	74.358	*a* 62.966+	1.181	Apr. 9
26	25	8.448	3.25	0	.....	.....	.....	Apr, 9
24	27.5	8.428	0.1	72.60	.....	.....	.....	Apr. 7
24	27.5	8.426	1.9	38.87	73.853	*a* 60.762—	1.212	Apr. 6
24	27.5	8.369	3.5	0	.....	.....	.....	Apr. 7
25	30	8.377	0.1	69.00	.....	.....	.....	Apr. 5
25	30	8.450	1.9	38.95	74.005	*b* 61.902—	1.196	Apr. 6
25	30	8.425	3.7	0	.....	.....	.....	Apr. 5
28	32.5	8.437	0.1	67.07	.....	.....	.....	Apr. 4
28	32.5	8.391	2.1	34.49	72.429	*c* 61.142—	1.184	Apr. 4
28	32.5	8.379	3.9	0	.....	.....	.....	Apr. 4
27	35	8.473	0.1	63.65	.....	.....	.....	Apr. 3
27	35	8.401	2.1	33.74	70.854	*d* 61.370+	1.154	Apr. 3
27	35	8.454	4.1	0	.....	.....	.....	Apr. 2

a Wind, 8.432 miles per hour.
b Wind, 8.455 miles per hour.
c Wind, 8.398 miles per hour.
d Wind, 8.395 miles per hour.

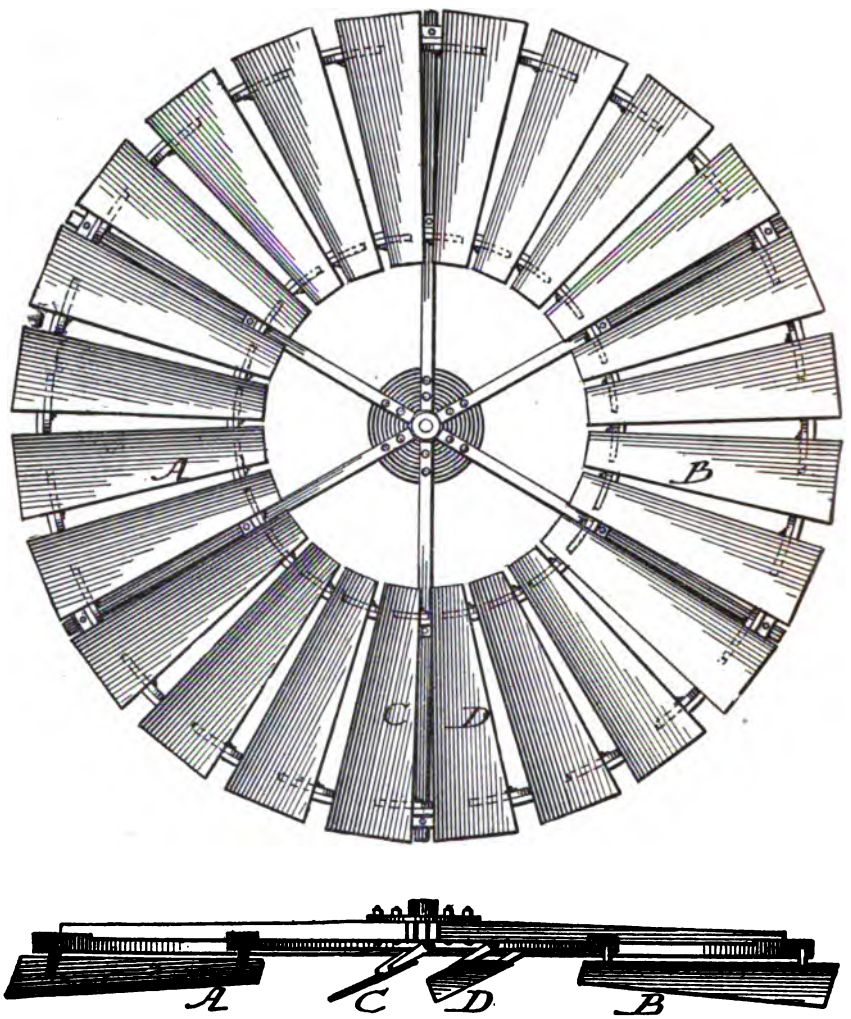


FIG. 16.—Elevation and section of wheel No. 24. (Sail area, 15.000 square feet; efficiency, 0.187).

Wheels Nos. 24 to 28 differed from each other only in angles of weather, each having 24 plain sails 18 inches long, 7 inches wide at outer ends, and 3 inches wide at inner ends. Wheels otherwise the same as No. 6.

Total area of sail surface, 15.000 square feet.

WHEELS NOS. 29 TO 33.—*Results of experiments.*

No. of wheel.	Angle of weather-er.	Velocity of wind per hour.	Load applied +0.1 for friction.	Turns of wheel per minute.	Product at maximum.	Product of No. 2 at maximum.	Ratio of products.	Date.
	°	*Miles.*	*Pounds.*					1883.
33	25	8.434	0.1	75.46	.....	.....	.....	Mar. 14
33	25	8.401	1.9	37.80	71.820	*a* 62.463—	1.150	Mar. 14
33	25	8.341	3.5	0	.....	.....	.....	Mar. 14
29	27.5	8.421	0.1	73.10	.....	.....	.....	Mar. 27
29	27.5	8.406	1.9	39.10	74.290	*b* 61.845—	1.201	Mar. 27
29	27.5	8.454	3.7	0	.....	.....	.....	Mar. 27
30	30	8.348	0.1	69.18	.....	.....	.....	Mar. 29
30	30	8.429	2.1	35.15	73.815	*c* 62.478+	1.181	Mar. 28
30	30	8.399	4.0	0	.....	.....	.....	Mar. 28
31	32.5	8.407	0.1	66.73	.....	.....	.....	Mar. 30
31	32.5	8.418	2.1	34.94	73.374	*d* 61.864—	1.186	Mar. 30
31	32.5	8.422	4.1	0	.....	.....	.....	Mar. 30
32	35	8.410	0.1	62.90	.....	.....	.....	Mar. 31
32	35	8.454	2.1	33.43	70.203	*e* 61.408+	1.143	Mar. 31
32	35	8.444	4.3	0	.....	.....	.....	Mar. 31

a Wind, 8.403 miles per hour.
b Wind, 8.410 miles per hour.
c Wind, 8.427 miles per hour.
d Wind, 8.419 miles per hour.
e Wind, 8.446 miles per hour.

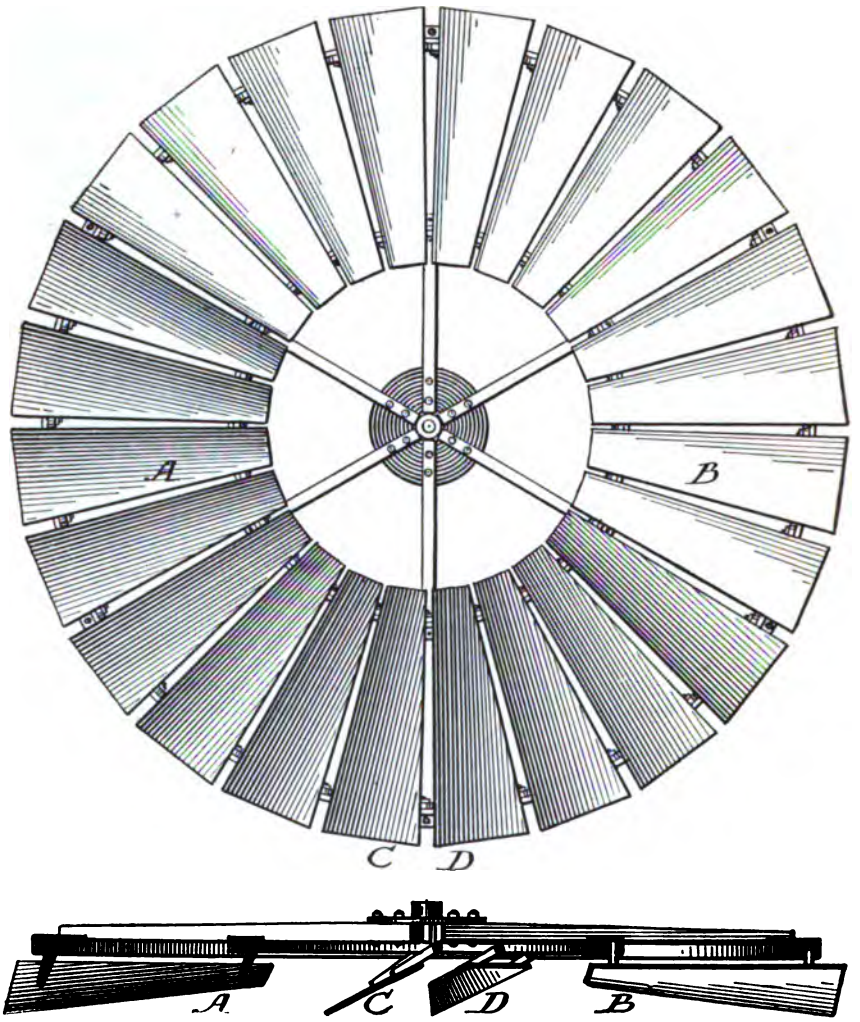


FIG. 17.—Elevation and section of wheel No. 29. (Sail area, 17.016 square feet; efficiency, 0.185.)

Wheels Nos. 29 to 33 differed from each other only in angles of weather, each having 24 plain sails 18 inches long, $8\frac{1}{16}$ inches wide at outer ends, and $3\frac{9}{32}$ inches wide at inner ends.

Total area of sail surface, 17.016 square feet.

Wheels otherwise the same as No. 6.

Dynamometer improved by addition of antifriction wheels and automatic brake adjuster, first used March 13, 1883, with wheel No. 33.

WHEELS NOS. 19, 20, AND 34.—*Results of experiments.*

No. of wheel.	Angle of weather.	Velocity of wind per hour.	Load applied +0.1 for friction.	Turns of wheel per minute.	Product at maximum.	Product of No. 2 at maximum.	Ratio of products.	Date.
	°	*Miles.*	*Pounds.*					1883.
19	27.5	8.471	0.1	74.94	.....	.....	.....	Apr. 12
19	27.5	8.500	1.9	39.57	75.183	*a* 62.719+	1.204	Apr. 11
19	27.5	8.455	3.3	0	.....	.....	.....	Apr. 11
20	30	8.464	0.1	70.78	.....	.....	.....	Apr. 14
20	30	8.486	1.9	39.87	75.753	*b* 62.966—	1.203	Apr. 13
20	30	8.475	3.55	0	.....	.....	.....	Apr. 14
34	25, 35	8.498	0.1	76.47	.....	.....	.....	Apr. 19
34	25, 35	8.502	1.7	43.77	74.409	*c* 61.655+	1.207	Apr. 18
34	25, 35	8.487	3.5	0	.....	.....	.....	Apr. 19

a Wind, 8.499 miles per hour. *b* Wind, 8.487 miles per hour. *c* Wind, 8.501 miles per hour.

Wheels Nos. 19, 20, and 34 differed from No. 18 only in angles of weather.

The sails of No. 34 were twisted, making angles of weather 25 degrees at outer ends of sails and 35 degrees at inner ends.

WHEELS NOS. 35 TO 38.—*Results of experiments.*

No. of wheel.	Angle of weather.	Velocity of wind per hour.	Load applied +0.1 for friction.	Turns of wheel per minute.	Product at maximum.	Product of No. 2 at maximum.	Ratio of products.	Date.
	°	*Miles.*	*Pounds.*					1883.
38	22.5	8.524	0.1	84.65	.....	.....	.....	Apr. 28
38	22.5	8.488	1.5	52.51	78.765	*a* 63.802=	1.235	Apr. 28
38	22.5	8.521	2.9	0	.....	.....	.....	Apr. 28
36	25	8.525	0.1	80.67	.....	.....	.....	Apr. 26
36	25	8.499	1.7	47.05	79.985	*b* 62.852—	1.273	Apr. 26
36	25	8.413	3.1	0	.....	.....	.....	Apr. 26
35	27.5	8.413	0.1	76.78	.....	.....	.....	Apr. 24
35	27.5	8.424	1.7	46.64	79.288	*c* 63.726—	1.244	Apr. 25
35	27.5	8.445	3.4	0	.....	.....	.....	Apr. 25
37	30	8.459	0.1	73.12	.....	.....	.....	Apr. 27
37	30	8.477	1.9	40.41	76.779	*d* 62.928	1.220	Apr. 27
37	30	8.473	3.6	0	.....	.....	.....	Apr. 27

a Wind, 8.488 miles per hour. *c* Wind, 8.425 miles per hour.
b Wind, 8.500 miles per hour. *d* Wind, 8.478 miles per hour.

Wheels Nos. 35, 36, 37, and 38 contained 12 plain sails of lineal dimensions, as shown in fig. 19. Each sail made by fastening together 2 sails of No. 18. Wheels otherwise the same as No. 18, and differed from each other only in angles of weather.

Total area of sail surface, 12.937 square feet.

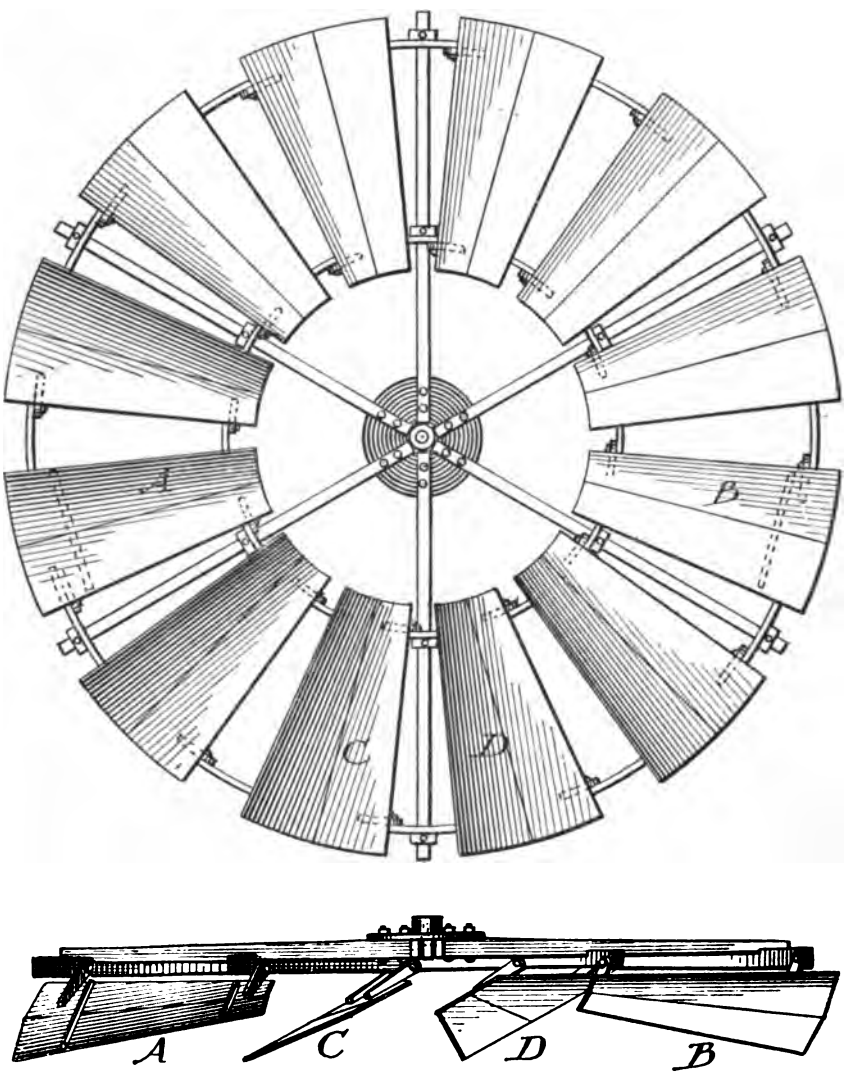


FIG. 18.—Elevation and section of wheel No. 35. (Sail area, 12.937 square feet; efficiency, 0.192.)

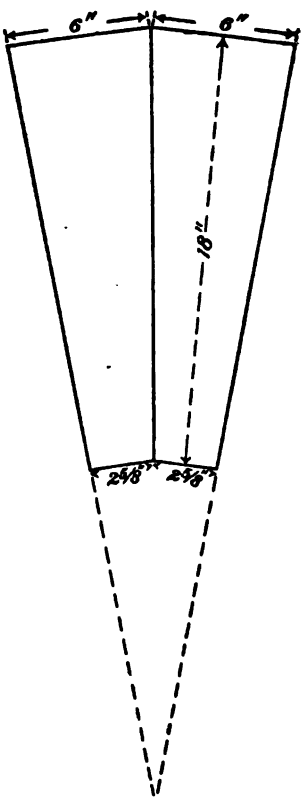


FIG. 19.—Dimensions of sails of wheels.
Nos. 35, 36, 37, and 38.

WHEELS NOS. 40 TO 43.—*Results of experiments.*

No. of wheel.	Angle of weather.	Velocity of wind per hour.	Load applied +0.1 for friction.	Turns of wheel per minute.	Product at maximum.	Product of No. 2 at maximum.	Ratio of products.	Date.
	°	*Miles.*	*Pounds.*					1883.
41	25	8.461	0.1	84.70	.....	.....	.....	May 5
41	25	8.496	1.9	46.81	88.939	65.474=	1.358	May 5
41	25	8.496	3.45	0	.....	.....	.....	May 5
40	27.5	8.498	0.1	82.13	.....	.....	.....	May 3
40	27.5	8.459	1.9	45.74	86.906	62.928=	1.381	May 3
40	27.5	8.519	3.75	0	.....	.....	.....	May 3
42	30	8.491	0.1	77.95	.....	.....	.....	May 7
42	30	8.464	1.9	43.15	81.985	61.180=	1.339	May 7
42	30	8.475	3.9	0	.....	.....	.....	May 7
43	25, 30	8.528	0.1	84.92	.....	.....	.....	May 8
43	25, 30	8.476	1.9	45.92	87.248	62.396=	1.398	May 8
43	25, 30	8.495	3.6	0	.....	.....	.....	May 8

Wind for No. 2 the same as for wheel compared in each case. Wheels contained 12 angular concave sails of lineal dimensions as shown in fig. 21. Each sail made by fastening together two sails of No. 18 at an angle of 165 degrees so as to present concave surface to the wind. Wheels differed only in angles of weather. The sails of No. 43 were twisted, making the angles of weather 25 degrees at outer ends of sails and 30 degrees at inner ends. Total area of sail surface, 12.937 square feet.

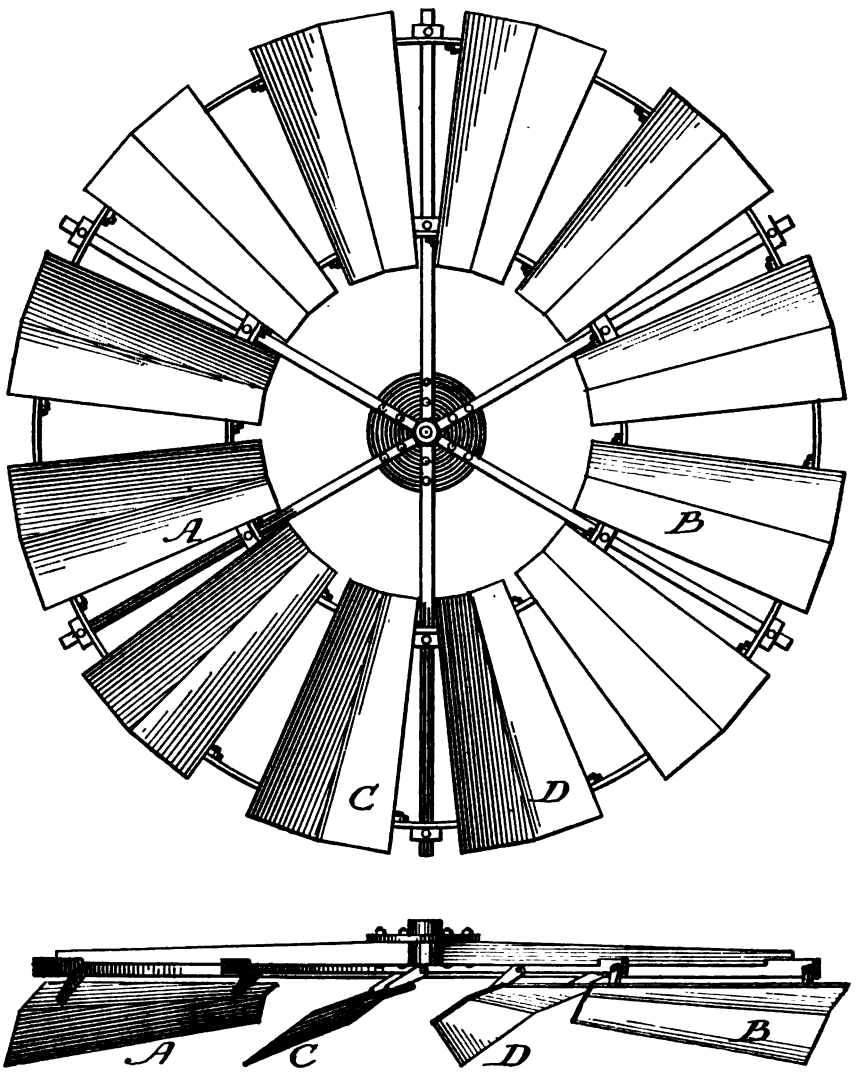


FIG. 20.—Elevation and section of wheel No. 40. (Sail area, 12.937 square feet; efficiency, 0.213.)

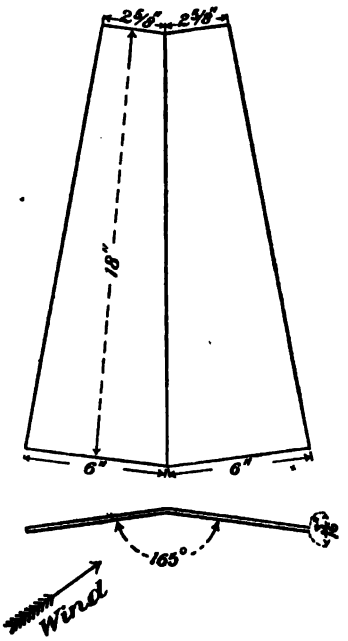


FIG. 21.—Dimensions of concave sails of wheels Nos. 40, 41, 42, and 43.

WHEELS NOS. 40 TO 42.—*Results of experiments.*

No. of wheel.	Angle of weather.	Velocity of wind per hour.	Load applied +0.1 for friction.	Turns of wheel per minute.	Product at maximum.	Product of No. 2 at maximum.	Ratio of products.	Date.
	°	*Miles.*	*Pounds.*					1883.
41	25	6.444	0.1	65.33	.....	.....	.....	May 24
41	25	10.963	0.1	111.10	.....	.....	.....	May 29
41	25	6.459	1.1	35.07	38.577	28.270=	1.365	May 24
41	25	11.022	3.3	55.45	182.985	*a*137.346+	1.332	May 29
41	25	6.404	2.0	0	.....	.....	.....	May 24
41	25	11.111	5.6	0	.....	.....	.....	May 29
40	27.5	6.372	0.1	60.27	.....	.....	.....	May 14
40	27.5	10.890	0.1	106.73	.....	.....	.....	May 21
40	27.5	6.371	1.1	32.90	36.190	26.290=	1.377	May 14
40	27.5	11.041	3.3	56.32	185.856	135.498=	1.372	May 17
40	27.5	6.403	2.1	0	.....	.....	.....	May 14
40	27.5	10.944	6.3	0	.....	.....	.....	May 21
42	30	6.454	0.1	59.13	.....	.....	.....	May 23
42	30	10.974	0.1	103.50	.....	.....	.....	May 23
42	30	6.429	1.2	29.65	35.580	26.037=	1.367	May 23
42	30	10.997	3.7	50.62	187.294	138.897=	1.348	May 22
42	30	6.411	2.3	0	.....	.....	.....	May 23
42	30	11.063	6.9	0	.....	.....	.....	May 22

a Wind, 11.021 miles per hour.

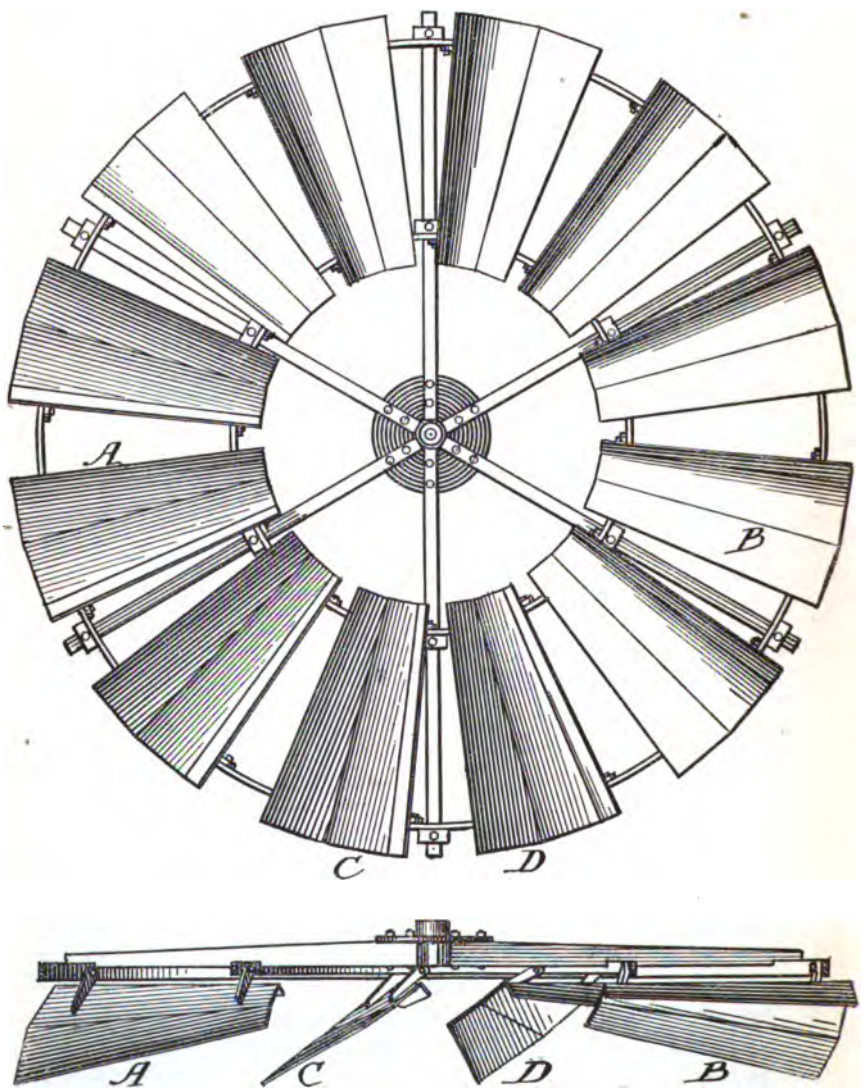


FIG. 22.—Elevation and section of wheel No. 39. (Sail area, 13.072 square feet; efficiency, 0.164.)

WHEELS NOS. 35, 39, 40, AND 44.—*Results of experiments.*

No. of wheel.	Angle of weather.	Velocity of wind per hour.	Load applied +0.1 for friction.	Turns of wheel per minute.	Product at maximum.	Product of No. 2 at maximum.	Ratio of products.	Date.
	°	*Miles.*	*Pounds.*					1883.
35	27.5	8.413	0.1	76.78	.....	.....	.....	Apr. 24
35	27.5	8.424	1.7	46.64	79.288	a63.726—	1.244	Apr. 25
35	27.5	8.445	3.4	0	.....	.....	.....	Apr. 25
39	27.5	8.472	0.1	64.52	.....	.....	.....	May 1
39	27.5	8.512	1.9	35.57	67.583	63.650=	1.062	May 1
39	27.5	8.431	3.7	0	.....	.....	.....	May 1
40	27.5	8.498	0.1	82.13	.....	.....	.....	May 3
40	27.5	8.459	1.9	45.74	86.906	62.928=	1.381	May 3
40	27.5	8.519	3.75	0	.....	.....	.....	May 3
44	25, 30	8.482	0.1	84.88	.....	.....	.....	May 9
44	25, 30	8.477	1.9	44.35	84.265	60.952=	1.382	May 9
44	25, 30	8.475	3.6	0	.....	.....	.....	May 9

a Wind, 8.425 miles per hour.

Wheel No. 39 contained 12 sails of lineal dimensions as shown in fig. 23, made by adding to the sails of No. 35, along their rear edges, strips as illustrated, so as to present concave surface to the wind. But the line *a b* was considered the face of the sail as regards angle of weather. For No. 40 see previous description. Sails angular concave.

Wheel No. 44 was the same as No. 3 except that the angles of weather were 25 degrees at outer ends of sails and 30 degrees at inner ends. Sails circular concave.

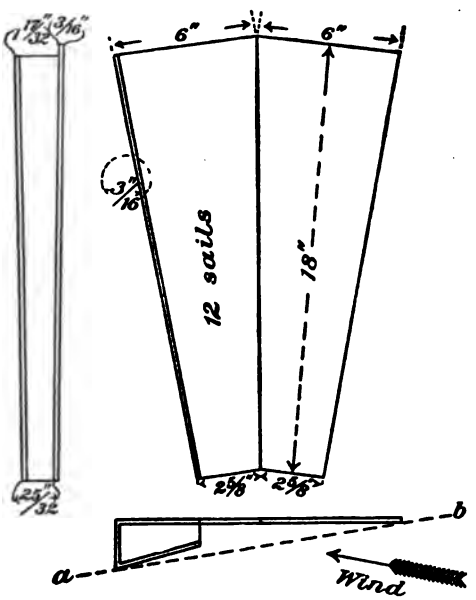


FIG. 23.—Dimensions of sails of wheel No. 39.

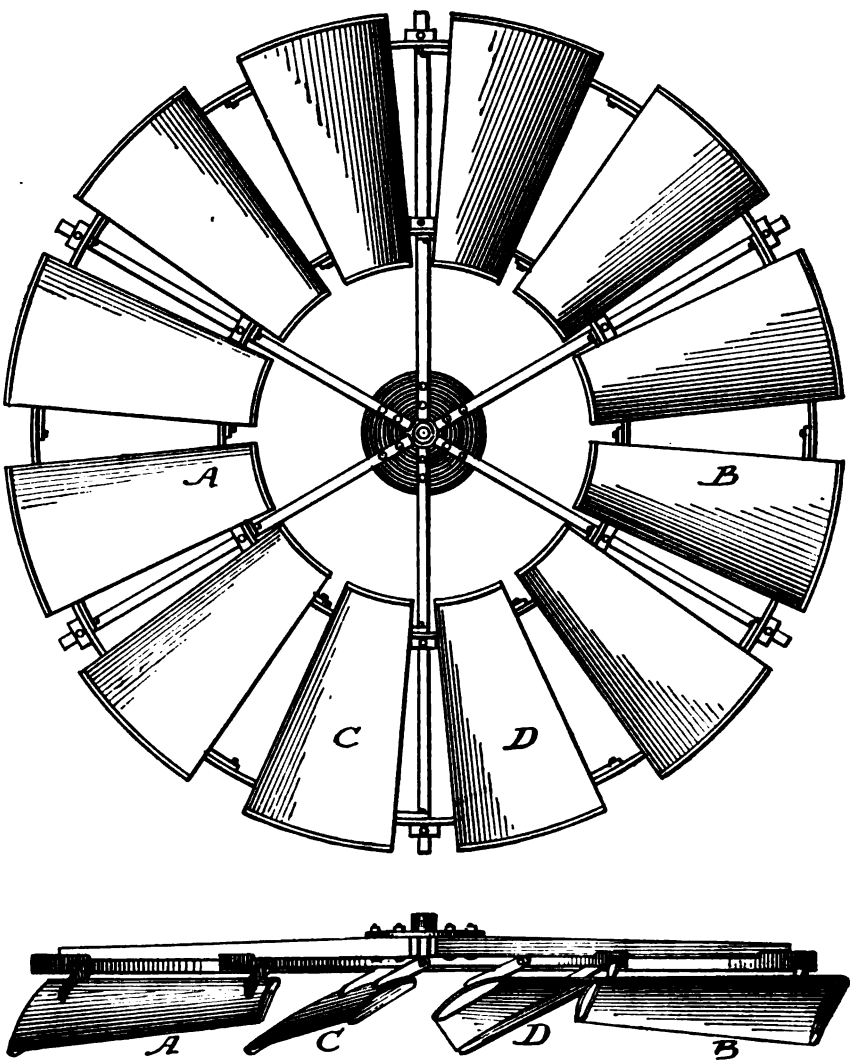


FIG. 24.—Elevation and section of wheel No. 44. (Sail area, 13.590 square feet; efficiency, 0.213.)

WHEELS NOS. 45 TO 49.—*Results of experiments.*

No. of wheel.	Angle of weather. *a*	Velocity of wind per hour.	Load applied +0.1 for friction.	Turns of wheel per minute.	Product at maximum.	Product of No. 2 at maximum.	Ratio of products.	Date.
	°	*Miles.*	*Pounds.*					1883.
46	17.5 at *ab*	11.025	0.1	160.90	.....	.....	.....	June 25
46	20 at *cd*	10.979	2.7	85.19	230.013	*b*135.201—	1.701	June 25
46	25 at *ef*	10.905	4.8	0	.....	.....	.....	June 25
	27.5 at *gh*							
45	20 at *ab*	10.918	0.1	156.63	.....	.....	.....	June 21
45	22.5 at *cd*	11.001	2.9	79.99	231.971	*c*129.195+	1.796	June 20
45	27.5 at *ef*	11.021	5.2	0	.....	.....	.....	June 21
	30 at *gh*							
47	22.5 at *ab*	11.026	0.1	148.68	.....	.....	.....	June 27
47	25 at *cd*	10.980	3.3	73.31	241.923	132.264=	1.829	June 26
47	30 at *ef*	10.944	6.0	0	.....	.....	.....	June 27
	32.5 at *gh*							
48	25 at *ab*	11.125	0.1	141.97	.....	.....	.....	June 27
48	27.5 at *cd*	10.935	3.7	66.79	247.123	132.033=	1.872	June 28
48	32.5 at *ef*	11.014	6.5	0	.....	.....	.....	June 28
	35 at *gh*							
49	27.5 at *ab*	11.187	0.1	136.30	.....	.....	.....	June 29
49	30 at *cd*	10.994	3.9	58.82	229.398	127.116=	1.805	June 29
49	35 at *ef*	10.993	6.6	0	.....	.....	.....	July 2
	37.5 at *gh*							

a Letters in this column refer to fig. 26, p. 61.

b Wind, 10.980 miles per hour.

c Wind, 11.000 miles per hour.

$1.09 = \frac{u}{v} = x =$ ratio of velocity of wind to velocity of outer extremities of sails of No. 48 for maximum work. See page 71.

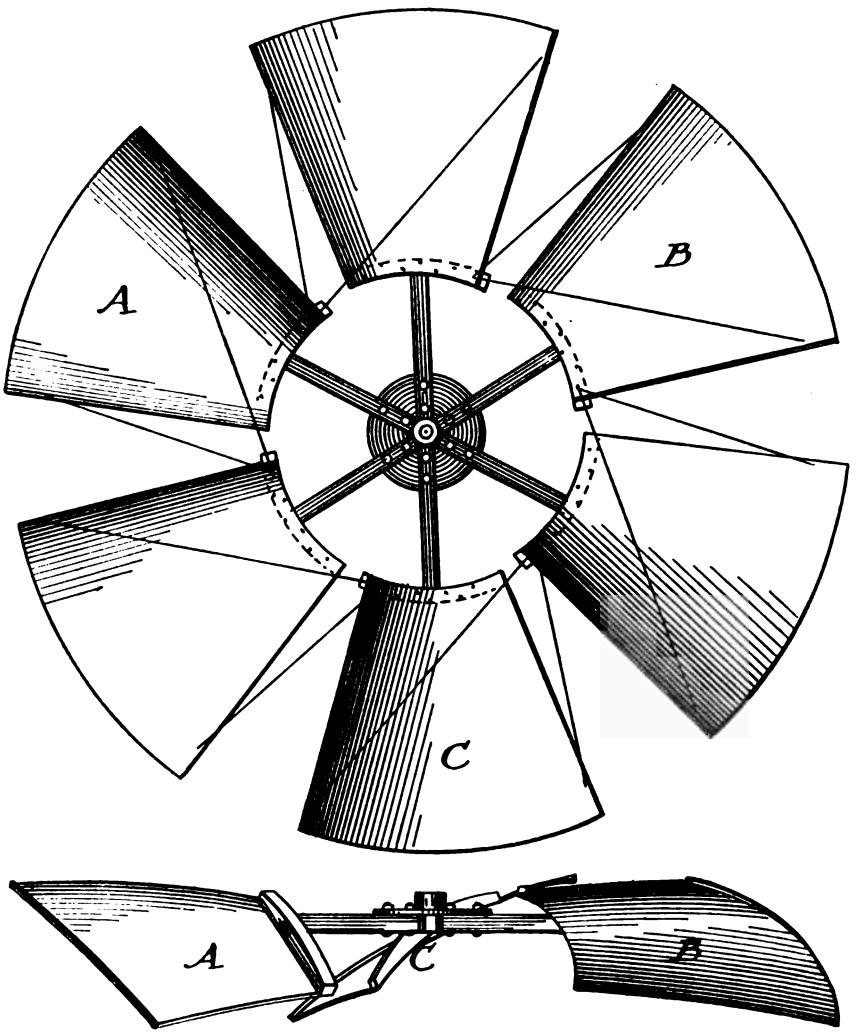


FIG. 25.—Elevation and section of wheel No. 48. (Sail area, 14.159 square feet; efficiency, 0.283.)

Wheels Nos. 45 to 49 differed from each other only in angles of weather, and contained six sails of lineal dimensions as shown in fig. 26. Sails were made by gluing together several layers of paper which formed pasteboard about one-sixteenth of an inch thick. The backs of front and rear edges of each sail were bordered by thin pine strips. Backs of outer edges of sails were likewise bordered and held in shape by stiff curved pine pieces. The inner end of each sail was fastened securely to a thick curved pine piece, which was bolted against the outer end of a short ash arm, so that the sail could be turned on the bolt and set at any desired angle of weather. Thus the arms did not extend beyond the inner ends of the sails. The outer corners of each sail were held in position by two fine brass wires extending to the front inner corner of the succeeding sail. The front and rear edges also curved somewhat, so that the sails presented double concave surfaces to the wind. In constructing these wheels we aimed at avoiding all unnecessary obstruction to the passage of wind between the sails.

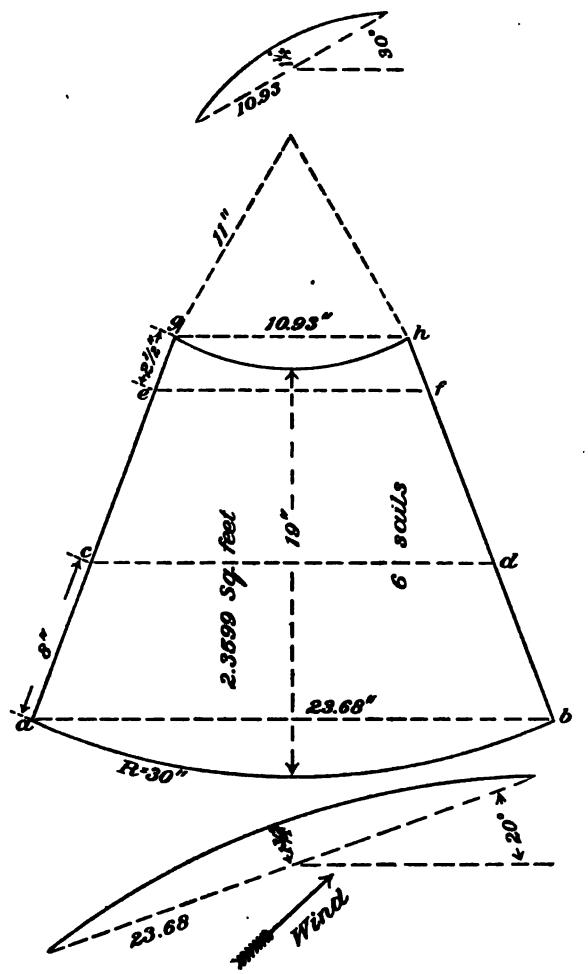


FIG. 26.—Dimensions of sails of wheels Nos. 45 to 49.

WHEELS NOS. 2, 60, AND 61.—*Results of experiments.*

No. of wheel.	Velocity of wind per hour.	Load applied ±0.1 for friction.	Turns of wheel per minute.	Product at maximum.	Product of No. 2 at maximum.	Ratio of products.	Date.
	Miles.	*Pounds.*					1883.
60	8.451	1.9	56.50	107.350	58.273—	1.842	Sept. 15
61	8.452	1.9	38.13	*a* 72.447	58.273=	1.243	Sept. 15
2	8.452	1.9	30.67	58.273	58.273=	1.000	Sept. 15

a This product may not have been a maximum, as only the one load, 1.9 pounds, was tried with No. 61.

Wheel No. 60 was the same as No. 48, except that the sails were considerably warped out of original shape from long standing and drying.

Wheel No. 61 was the same as No. 60, except that along the back of each sail a

rectangular piece of pine 1 by 1¼ by 17 inches was fastened to make an obstruction representing an extension of the arm, as illustrated in figs. 28 and 29.

The relative efficiency of No. 60 as compared with No. 61 is indicated by the equation

$$\frac{107.350}{72.447} = 1.482$$

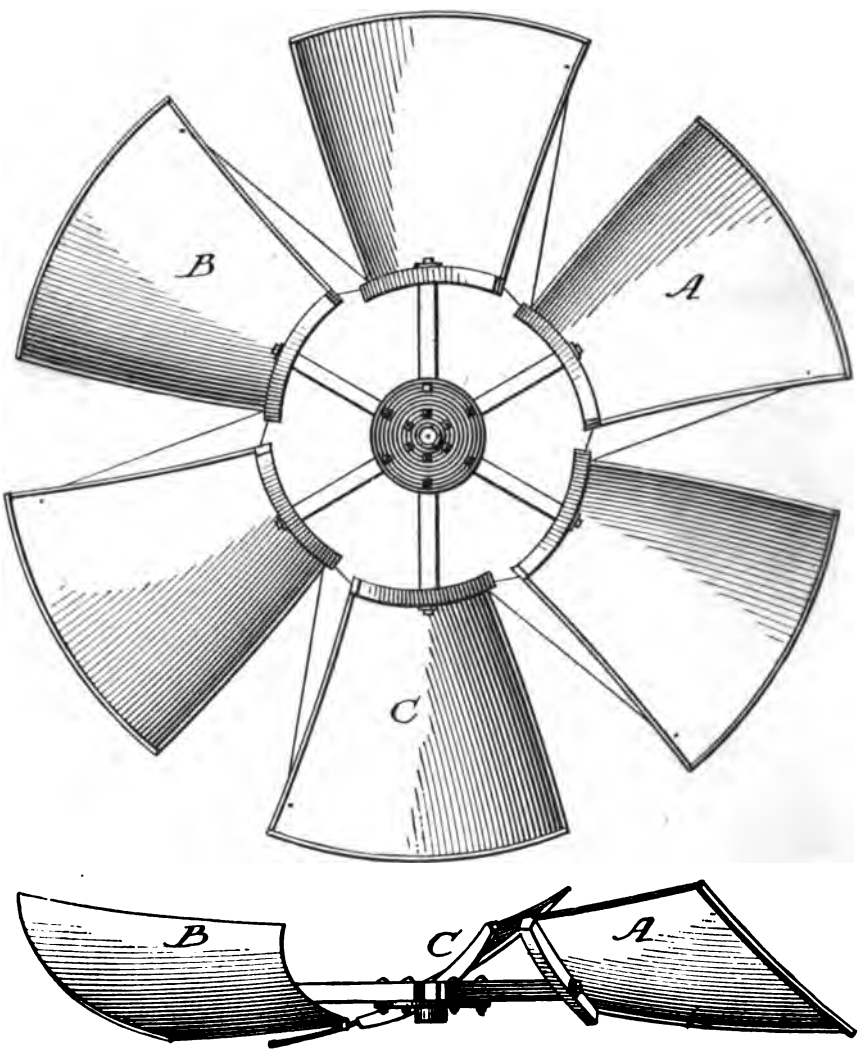


FIG. 27.—Elevation and section of wheel No. 60. (Sail area, 14.159 square feet; efficiency, 0.284.)

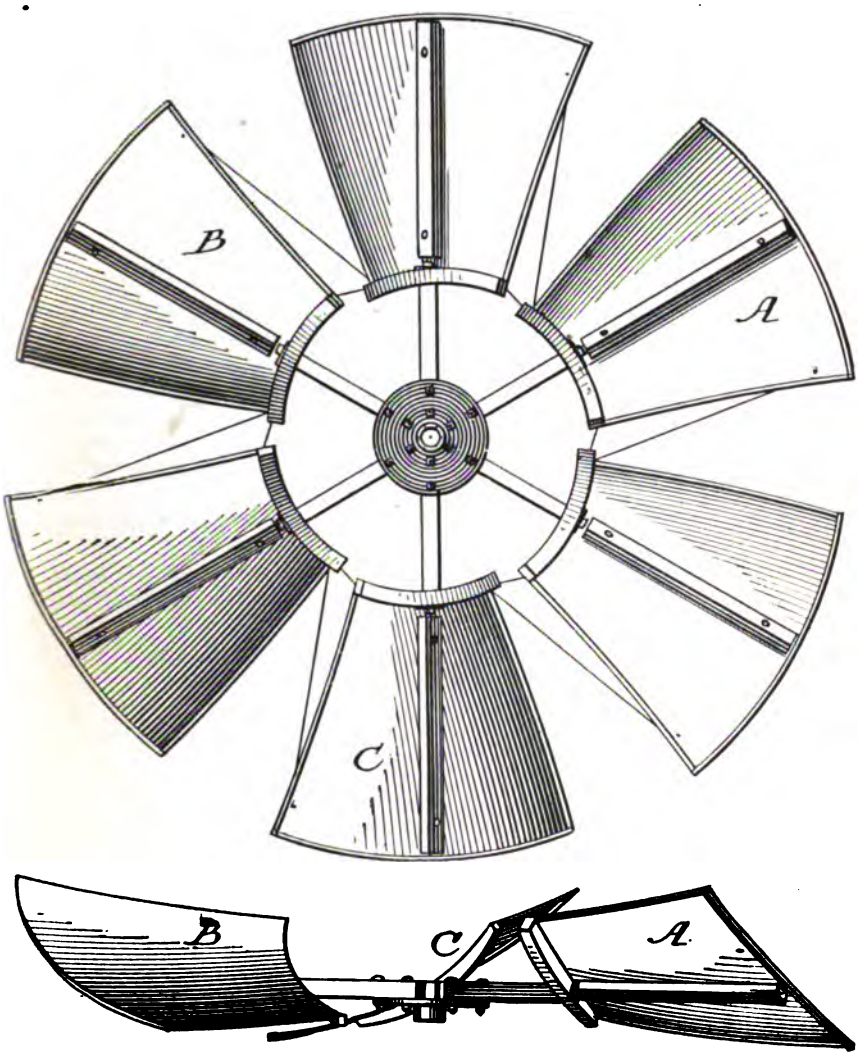


FIG. 28.—Elevation and section of wheel No. 61. (Sail area, 14.159 square feet; efficiency, 0.191.)

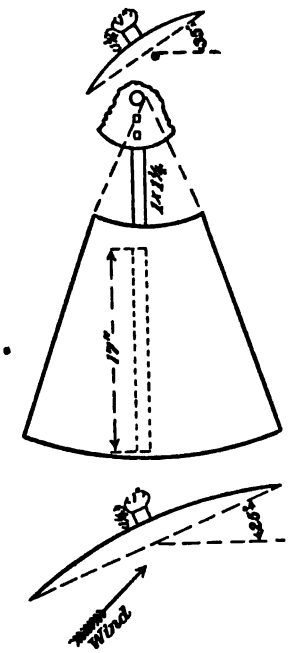


FIG. 29.—Dimensions of sails of wheel No. 61 with obstruction on back.

WHEELS NOS. 2, 49, AND 53 TO 57.—*Results of experiments.*

No of wheel.	Angle of deflector.	Velocity of wind per hour.	Loads applied +0.1 for friction.	Turns of wheel per minute.	Date.
	°	*Miles.*	*Pounds.*		1883.
54	30	10.989	0.1	79.40	July 3
53	45	11.156	0.1	81.80	July 3
55	60	10.985	0.1	80.52	July 3
2	.....	11.007	0.1	77.57	July 3
2	.....	10.975	3.3	37.83	July 5
56	50	10.968	3.3	40.63	July 5
57	50	11.054	3.5	62.63	July 5
49	.....	11.032	3.5	64.22	July 5

Wheels Nos. 53, 54, 55, and 56 were the No. 2 wheel, with stationary rectangular board, $\frac{1}{4}$ by $9\frac{3}{16}$ by 22 inches, placed in front of sails and with its face set at various angles with plane of wheel, as indicated in table, to act as deflector. Board supported by arm outside of wheel on side farthest from axis of sweep; its lower edge at height of axis of wheel, horizontal, and parallel to plane of wheel. Inner end of board 9 inches from axis of wheel prolonged.

Wheel No. 57 was wheel No. 49, with the same board, described above, similarly used as deflector, except that its lower edge was placed so as to clear the forward edges of sails by about 2 inches at each end.

In the case of Nos. 53 to 56 the center of board deflector was about 7 inches from center of sails.

WHEELS NOS. 2, 49, 51, 52, 58, AND 59.—*Results of experiments.*

No. of wheel.	Position of obstruction.	Velocity of wind per hour.	Load applied +0.1 for friction.	Turns of wheel per minute.	Date.
		Miles.	*Pounds.*		1883.
2	.....	11.141	0.1	78.58	July 3
51	Before ..	11.130	0.1	75.73	July 3
52	Behind..	11.045	0.1	76.16	July 3
49	.....	10.966	3.5	64.53	July 5
58	Before ..	10.972	3.5	55.54	July 5
59	Behind..	10.972	3.5	60.06	July 5

Wheel No. 51 was No. 2, with rectangular board ¼ by 9⅛ by 22 inches placed horizontally in front of the side of wheel farthest from axis of sweep, its face parallel to plane of wheel so as to act as obstruction to wind. Board held at its outer end by means of an arm outside of wheel.

Distance from board to centers of sails, 8 inches.

Distance from inner end of board to axis of wheel prolonged, 9 inches.

Wheel No. 52 was the same as No. 51, except that the board was placed 8 inches behind centers of sails.

Wheel No. 58 was No. 49, with obstrution board above described similarly placed, 8½ inches in front of centers of sails.

Wheel No. 59 was the same as No. 58, except that the board was placed 8½ inches behind centers of sails.

SAILS AT BEST ANGLES OF WEATHER.

Efficiency of various wind wheels at best angles of weather.

No. of wheel.	Area of sail surface.	Angles of weather.	Wind per hour.	Turns of wheel unloaded.	Starting forces.	Load at maximum.	Turns of wheel at maximum.	Product at maximum.	Product of No. 2 at maximum.	Ratio of products.	Value per square foot of sail surface.	Number and indicated character of sails.
	Sq. ft.	°	*Miles.*		*Lbs.*	*Lbs.*						
1	9.190	35	8.452	60.0	.....	1.6	31.69	50.704	.....	.....	.....	30
2	18.380	35	8.403	59.0	4.1	1.9	32.875	62.463	62.463	1.000	0.0544	60
10	10.688	27.5	8.338	72.0	.....	1.7	39.33	66.861	.....	.....	.....	24
19	12.937	27.5	8.500	75.5	3.2	1.9	39.57	75.183	62.719	1.204	.0931	24
34	12.937	25, 35	8.502	76.5	3.4	1.7	43.77	74.409	61.655	1.207	.0938	24
24	15.000	27.5	8.426	72.7	3.4	1.9	38.87	73.853	60.762	1.212	.0808	24
29	17.016	27.5	8.406	73.0	3.6	1.9	39.10	74.290	61.845	1.201	.0706	24
35	12.937	27.5	8.424	77.0	3.3	1.7	46.64	79.288	63.726	1.244	.0962	12
36	12.937	25	8.499	80.0	3.0	1.7	47.05	79.988	62.852	1.273	.0984	12
44	13.590	25, 30	8.477	85.0	3.5	1.9	44.35	84.265	60.953	1.382	.1017	12
40	12.937	27.5	8.459	81.5	3.6	1.9	45.74	86.906	62.928	1.381	.1067	12
43	12.937	25, 30	8.476	84.5	3.5	1.9	45.92	87.248	62.396	1.398	.1081	12
48	14.159	25, 27.5 32.5, 35	10.935	141.0	6.1	3.7	66.79	247.123	132.033	1.872	.1322	6

The velocities of wind given in this table are strictly correct only for products at maximum, though they are very nearly correct also for products of No. 2 at maximum. The velocities of wind are only approximately correct for turns of wheels unloaded and for starting forces. Nothing was added to starting forces for friction, and the 0.1 pound was added to starting forces in preceding tables only for convenience.[1] For further particulars consult preceding tables.

RELATIONS OF THREE DIFFERENT VELOCITIES OF WIND.

Relation of different velocities of wind to maximum products.

Angle of weather.	No. of wheel.	Wind per hour.		Product at maximum.		$\frac{b}{a}$	$(\frac{b}{a})^3$	$\frac{B}{A}$	$\frac{B}{A}-(\frac{b}{a})^3$	$A\times(\frac{b}{a})^3$
		a	b	A	B					
°		*Miles.*	*Miles.*							
35	2	6.371	8.459	26.290	62.928	1.328—	2.342	2.394	+0.052	61.571
	2	8.459	11.041	62.928	135.498	1.305+	2.223	2.153	— .070	139.889
	2	6.371	11.041	26.290	135.498	1.733	5.199	5.154	— .045	136.682
27.5	40	6.371	8.459	36.190	86.906	1.328—	2.342	2.401	+ .059	84.757
	40	8.459	11.041	86.906	185.856	1.305+	2.223	2.139	— .084	193.192
	40	6.371	11.041	36.190	185.856	1.733	5.199	5.135	— .064	188.152
25	41	6.459	8.496	38.577	88.939	1.315+	2.274+	2.306	+ .032	87.724
	41	8.496	11.022	88.939	182.985	1.297+	2.182	2.057+	— .125	194.065
	41	6.459	11.022	38.577	182.985	1.706+	4.965+	4.743	— .222	191.535
30	42	6.429	8.464	35.580	81.985	1.317+	2.284+	2.304+	+ .020	81.265
	42	8.464	10.997	81.985	187.294	1.299+	2.192	2.284+	+ .092	179.711
	42	6.429	10.997	35.580	187.294	1.707+	4.974	5.264	+ .290	176.975

Conclusion.—Maximum products vary as the cubes of the velocities of wind. Some allowance must be made for the differences in time and condition of air under which the various products were obtained; considering these differences, there is no unaccountable variation from the law of cubes.

Relation of different velocities of wind to starting forces.

Angle of weather.	No. of wheel.	Wind per hour.		Starting forces.		$\frac{b}{a}$	$(\frac{b}{a})^3$	$\frac{B}{A}$
		a	b	A	B			
°		*Miles.*	*Miles.*	*Pounds.*	*Pounds.*			
35	2	6.380	8.405	2.3	4.1	1.319—	1.740	1.783
	2	8.405	10.989	4.1	7.0	1.307	1.708	1.704
	2	6.380	10.989	2.3	7.0	1.722	2.965	3.043
27.5	40	6.403	8.519	2.0	3.65	1.330	1.769—	1.825
	40	8.519	10.944	3.65	6.2	1.285	1.651	1.699
	40	6.403	10.944	2.0	6.2	1.709	2.921—	3.100
25	41	6.404	8.496	1.9	3.35	1.327—	1.761	1.763
	41	8.496	11.111	3.35	5.5	1.308—	1.711—	1.642
	41	6.404	11.111	1.9	5.5	1.735	3.010	2.895
30	42	6.411	8.475	2.2	3.8	1.322	1.748	1.727
	42	8.475	11.063	3.8	6.8	1.305—	1.703	1.789
	42	6.411	11.063	2.2	6.8	1.725	2.976—	3.091

Conclusion.—Starting forces vary as the squares of the velocities of wind.

[1] See starting forces, "S," p. 25.

Relation of different velocities of wind to speed of unloaded wheels.

Angle of weather.	Nos. of wheels.	Wind per hour.		Turns unloaded.		$\frac{b}{a}$	$\frac{B}{A}$
		a	*b*	*A*	*B*		
°		*Miles.*	*Miles.*				
35	2	6.437	8.511	43.78	59.62	1.322	1.362
	2	8.511	10.996	59.62	78.68	1.292	1.320
	2	6.437	10.996	43.78	78.68	1.708	1.797
27½	40	6.372	8.498	60.27	82.13	1.334	1.363
	40	8.498	10.890	82.13	106.73	1.281	1.300
	40	6.372	10.890	60.27	106.73	1.709	1.771
25	41	6.444	8.461	[1]65.33	84.70	1.313	1.296
	41	8.461	10.963	84.70	111.10	1.296	1.312
	41	6.444	10.963	[1]65.33	111.10	1.701	1.701
30	42	6.454	8.491	59.13	77.95	1.316	1.318
	42	8.491	10.974	77.95	103.50	1.292	1.328
	42	6.454	10.974	59.13	103.50	1.700	1.750

[1] Too great because of outside wind and perhaps other causes.

Conclusion.—Speeds of unloaded wheels increase in somewhat greater ratio than the velocities of wind.

All wind wheels tested were 5 feet in external diameter, and all sails were 18 inches long except in the case of Nos. 46 to 49 and Nos. 60 and 61, in which wheels the sails were 19 inches long, 1 inch being added for support at inner ends.

AUTOMATIC BRAKE ADJUSTER.

On March 13, 1883, the dynamometer was improved by the addition of an automatic brake adjuster. Previous to this date the brake was adjusted as described on page 23 through regulating the tension of the adjusting cord by sliding a weight in and out on a lever attached to the cord.

This method required time and patience in order to get an exact balance between the load applied and the friction of brake, and it was also necessary to exercise judgment in determining when the balance was exactly even. Furthermore, an exact balance was not always retained during a test of one minute, as required for accuracy, and frequent readjustments were constantly necessary. The labor involved in adjusting and maintaining a proper balance of friction and load became very tiresome when kept up for from six to eight hours continuously, as was frequently the case; and weariness was detrimental to the perceptions as well as to the judgment. Therefore, an automatic adjuster became very desirable, both for relief to the mind and for the increase of accuracy.

The automatic brake adjuster, after various attempts and failures, was finally constructed as follows: The brake and adjusting cord were

left substantially as previously described on page 23; but one end of a short rod three-sixteenths inch in diameter was attached to the cord where it was brought back from the brake in a direction parallel to the axis of the shaft. The other end of this rod had a full thread, 32 to the inch, and a nut which was fastened to a wooden wheel *A*, 6½ inches in diameter. This wheel was supported on a hollow tube through which the rod passed, and against the outer end of which the nut rested. The nut communicated tension to the adjusting cord, which was tightened by revolving the wheel *A* in one direction and loosened by turning the wheel in the opposite direction. This wheel *A* was driven by a small wheel *B*, 1½ inches in diameter, fastened to a large wheel *C*, 5 inches in diameter. This wheel *C* was driven by another small wheel *D*, $1\frac{5}{16}$ inches in diameter, fastened to a large wheel *E*, 4 inches in diameter, the periphery of which was constantly in contact with another wheel *F* of the same dimensions. The wheels *E* and *F* were supported by a tilting frame which oscillated on a supporting rod passing through the centers of the wheels *B* and *C*, but not touching them. The wheels *E* and *F* hung in close proximity to the rear end of wind wheel shaft, $1\frac{3}{16}$ inches in diameter, so that a slight movement of the tilting frame would bring either of the wheels *E* or *F* in contact with the shaft; and if wheel *E* came in contact with the shaft while revolving, the adjusting cord would be drawn tighter, and if wheel *F* came in contact with the shaft, the tension of the cord would be relaxed. The tilting frame was connected with the brake and partook of its oscillating motion, so that if the friction of the brake was too small to lift the load applied, wheel *E* would be in contact with the shaft and would cause an increase in the friction of the brake until the load was lifted and contact between wheel *E* and the shaft broken. If the friction of the brake was too great, the load applied was raised until wheel *F* came in contact with the shaft so as to cause a diminution of friction until contact of wheel *F* with the shaft was broken. It was very easy to tell at any time if friction of brake was too little or too great, by simply watching the direction of movement of wheels *E* and *F*. This did not require the exercise of judgment, as errors of balance were greatly magnified to the eye and made self-correcting. All contacts between the various wheels, *A*, *B*, *C*, *D*, *E*, *F*, and shaft were frictional. Wheels *B*, *C*, were entirely supported by contact of peripheries with wheels *A* and *D*, and wheel *E* was so hung to a separately hinged support that its own weight produced a uniform pressure against wheel *F*. The entire automatic system was supported independently of the brake; the connection with the brake served only to give the necessary oscillatory movement to the tilting frame, which was also balanced both as regards the action of gravity and centrifugal force when the sweep was in motion.

Some power of the wheel was necessarily consumed by the automatic adjuster, but it may be ascertained, from the description and dimensions given, that a point in the wind wheel 1 foot from the center

of shaft would move in tightening the adjusting cord about 67,019 times as far as the threaded rod attached to the cord; from this it follows that the pressure of the brake against the cylinder was $67,019 \times 16 = 1,072,304$ times as great as the force required at 1 foot from the center of shaft to produce the pressure, without considering the friction of the automatic system. And if we make the very liberal allowance of one-third additional force required to overcome the friction of the automatic system and call the friction of brake 0.05 of pressure, remembering that the diameter of cylinder was $5\frac{1}{4}$ inches, we may readily find that the force required to produce friction of brake equal to any load would be only about $\frac{1}{13964}$ part of that load at the same distance from center of shaft. Hence, it will be seen that the power consumed by the automatic brake adjuster was too minute materially to affect products and called for no correction.

THEORY OF THE ACTION OF THE WIND UPON THE SAILS OF WINDMILLS.

Where a fluid moves along in a current, the direct force of the current is expressed in pounds by the formula Mv, in which v represents the velocity of flow in feet per second and M is the mass of fluid which flows per second past a fixed point. $M = \frac{W}{g}$, W representing weight in pounds of fluid passing the fixed point per second, and $g = 32.2$, the constant for gravity. [1]

Where a current acts against a surface and its direction is simply changed by the surface without impeding its velocity, a direct pressure $= Mv$ is exerted by the impinging current in the direction of its motion, and an equal pressure is exerted by the current as it escapes from the surface, $= Mv$, in a direction opposite to the direction of escape.

If the current impinges against a surface which is itself in motion, the relative velocities of the impinging and escaping currents must be considered in determining the forces which act upon the moving surface. Of the two equal forces due to impingement and escape of current the sum of those components acting in the direction of motion of the surface constitutes the useful effort designated by P, and if the velocity per second of motion of surface is called u, the useful work yielded per second by the current will be represented by Pu. The actual energy of the current is represented [2] by $\frac{Mv^2}{2} = \frac{Wv^2}{2g}$. The ratio of useful work to actual energy is termed efficiency, and is represented [3] by the symbol $1 - k = \frac{2Pug}{Wv^2}$.

In deducing formulæ to represent the action of wind upon the sails of windmills we have proceeded upon the assumption that the sail

[1] See Rankine's Steam Engine, articles 14 and 144, Case III.
[2] See Rankine's Steam Engine, article 31.
[3] See Rankine's Steam Engine, article 92.

should be of such form as most effectually to change the air current into a direction as nearly as possible opposite to the direction of the sail's motion. We have also assumed, in accordance with principles stated by Rankine concerning the action of water on vanes, that the receiving edge of the sail should be tangent to the relative direction of the impinging current. These conditions are represented in fig. 30, in which $DE = v$ = direction and velocity of wind, $AE = u$ = direction and velocity of sail, and α = angle DEA, which the direction of wind makes with direction of motion of sail.

Then, DA = relative direction and velocity of current with reference to sail AB.

Let $BG = AD$ = relative direction and velocity of current as it escapes from the sail.

β = angle BGF which relative direction of escaping current makes with direction of sail's motion.

Then

$$DC = v \sin \alpha.$$
$$AC = u - v \cos \alpha.$$
$$AD = \sqrt{v^2 \sin^2 \alpha + (u - v \cos \alpha)^2}.$$
$$GF = GB \cos \beta = AD \cos \beta.$$
$$GF = \cos \beta \sqrt{v^2 \sin^2 \alpha + u^2 - 2uv \cos \alpha + v^2 \cos^2 \alpha}.$$
$$GF = \cos \beta \sqrt{v^2 + u^2 - 2uv \cos \alpha}.$$

If Q = volume in cubic foot of air acting on sail in 1 second, and d = weight in pounds of 1 cubic foot of air, we have for useful effort

$$P = \frac{dQ}{g}(GF - AC).$$
$$P = \frac{dQ}{g}[\cos \beta \sqrt{u^2 + v^2 - 2uv \cos \alpha} - u + v \cos \alpha].$$

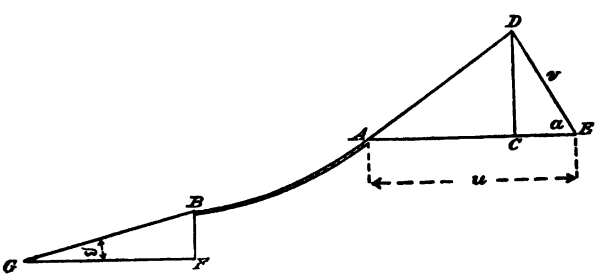


FIG. 30.—Action of wind on a sail.

The expression for useful work becomes

$$Pu = \frac{dQ}{g}[u \cos \beta \sqrt{u^2 + v^2 - 2uv \cos \alpha} - u^2 + uv \cos \alpha]. \qquad (A)$$

Dividing by $\frac{Mv^2}{2} = \frac{dQv^2}{2g}$ we have for efficiency

$$1 - k = 2\frac{u}{v} \cos \beta \sqrt{1 + \frac{u^2}{v^2} - 2\frac{u}{v} \cos \alpha} - 2\frac{u^2}{v^2} + 2\frac{u}{v} \cos \alpha.$$

Or letting $\frac{u}{v}=x$,

$$1-k=2x\cos\beta\sqrt{1+x^2-2x\cos\alpha}-2x^2+2x\cos\alpha. \qquad (B)$$

By substituting $-\cos\gamma$ for $\cos\beta$ in formula (A) the expression for Pu becomes the same as formula (6) on page 165 of Rankine's Steam Engine.

To find an expression for x corresponding to maximum efficiency, for general values of α and β would, as Rankine remarks, be more trouble than it is worth. But in the case of the windmill we know that $\alpha=90°$, which makes $\cos\alpha=0$. Hence, formula (B) becomes

$$1-k=2\cos\beta\sqrt{x^2+x^4}-2x^2. \qquad (C)$$

The relation between x and β corresponding to maximum and minimum efficiency will be expressed by the formula

$$x^2=-\tfrac{1}{2}\pm\tfrac{1}{2}\sqrt{\frac{1}{1-\cos^2\beta}}=-\tfrac{1}{2}\pm\frac{1}{2\sin\beta}. \qquad (D)$$

From this it appears that if $\beta=0$, as it should for maximum efficiency, x becomes infinite. That is, the theoretical efficiency of the windmill becomes greater as the speed of the sails increases indefinitely.

If $\beta=0$ formula (C) shows that

For $x=1$, $1-k=.828$; for $x=2$, $1-k=.944$;
For $x=3$, $1-k=.973$; for $x=10$, $1-k=.9974$;

or almost perfect efficiency when the speed of the sails is 10 times the velocity of the wind. Perfect efficiency, however, could not be reached unless $x=\infty$.

Of course the formula does not take into account the retarding effect of friction, resistance of medium, and other causes which make it impossible to realize in practice anything like the efficiency indicated by the formula; and in practice β can never equal 0 as it should for perfect efficiency.

Letting $x=1$ and assigning more probable values to β, formula (C) gives

For $\beta=10°$, $1-k=.785$.
For $\beta=20°$, $1-k=.657$.
For $\beta=30°$, $1-k=.449$.

Theoretically the analysis of the action of wind on the sails of a windmill corresponds to the analysis of the action of water on a reaction wheel or turbine without guide blades.[1] In the windmill, as commonly made, angle α in our formula (B) is necessarily 90°; but the formula suggests guide blades or deflectors corresponding to those of parallel-

[1] See Rankine's Steam Engine, pp. 197 and 206.

flow turbine water wheels. For if we give to x and β any probable finite values, we may find the values of angle α corresponding to maximum efficiency from the formula,

$$\cos \alpha = \tfrac{1}{2}\left(x + \frac{1}{x} - x \cos^2 \beta\right) \qquad \text{(E)}$$

in which—

For $x = 3$ and $\beta = 10°$, $\alpha = 77° 46'$;
For $x = 2$ and $\beta = 10°$, $\alpha = 73° 44'$;
For $x = 3$ and $\beta = 20°$, $\alpha = 70° 00'$;
For $x = 2$ and $\beta = 20°$, $\alpha = 68° 28'$;
For $x = 1$ and $\beta = 20°$, $\alpha = 56° 03'$.

These assumptions for x and β are plausible, as x varies greatly between the outer and inner extremities of a sail, and β should be assumed as the average angle of escape of the whole cylinder of air intercepted by the wheel, and not as the angle merely of that portion of air which comes immediately in contact with the sails, or which the sails directly intercept.

It is to be noticed that formula (B) does not take into account as such the angle of weather, which seems to be incidental to practice but not to theory.

As we have already pointed out, our formula (A) is substantially the same as Rankine's general formula for the action of water on vanes. But Rankine, instead of applying his general formula to windmills, breaks entirely away from it, and uses another formula specially deduced for the "case of a flat vane oblique to the jet," and which he calls the "easiest method of solution."[1] But that his "easiest method" is erroneous even in the case specified, is evidenced by the fact that a very different result is obtained by the application of his general formula.

We pointed out the nature of Rankine's error in a paper dated December, 1881, which was submitted to Prof. R. H. Thurston, of Stevens Institute of Technology. Other writers on windmills have made the same mistake. The theory and formula which we have here given are abstracted from a paper also prepared for Professor Thurston, dated March 6, 1882.

Theoretical considerations were kept in view during our dynamometric experiments. It will be seen from the preceding tables of experiments how closely the results obtained in practice correspond to theory.

DISCUSSION OF RESULTS.

THERMOMETRIC AND BAROMETRIC INFLUENCES.

The preceding pages are substantially an unchanged reproduction of the records made by the writer for the United States Wind Engine and Pump Company of Batavia, Illinois, during and immediately after the experiments in 1883. The only alteration we have presumed to

[1] See Rankine's Steam Engine, pp. 169 and 215.

make is in omiting the records of barometric readings which were made during the earlier experiments. No barometric readings were taken or recorded after December 21, 1882.

CONSTRUCTION OF TABLES.

In tables on pages 28 to 46 results are recorded for a greater or less number of loads increasing usually by increments of two-tenths pound. Although the results are always given in the order of increasing loads, they were not always obtained in that order, as is indicated by the marginal dates at the right-hand side of some of the tables. Enough tables were prepared in this manner to show how in general the speeds of revolution decreased as the loads increased, and how the products increased with the increasing loads up to a certain point, which marks the maximum, and then decreased continually with further increments of load until the vanishing point was reached. It was not necessary to try many different loads in order to find the best load corresponding to the maximum product. This could be ascertained by a few trials, and as our main object was to get at the relative merits of the wheels tested, we subsequently abandoned the practice of trying so many different loads, and confined our attention more strictly to the determination of maximum products, starting forces, and unloaded speeds; so that the remaining tables on pages 47 to 65 show in general only these three results for each wheel and comparisons of results with different wheels. Special explanations relative to special tables are given elsewhere.

EXTREME RESULTS.

In addition to the original tables already presented, we have collected together in the following table the maximum products given by wind wheel No. 2 at the various dates it was tested in connection with other wheels. It may be observed that the lowest maximum product was 58.083, recorded on April 10, 1883, and that the highest product for wind of nearly the same velocity was 65.474, recorded on May 5, 1883. The products for the same wheel thus vary nearly 13 per cent on different days. Taking the temperature and barometric pressure of Chicago on the two days above mentioned as approximately the same as at Batavia, 35 miles distant due west, we are able to account for but little more than 2 per cent of the variation. Notice also that in wind of about 11 miles per hour, the lowest maximum product was 124.839, recorded on July 5, 1883, and that the highest product was 138.897, recorded on May 22, 1883. Here a variation of over 11 per cent appears for the same wheel on different days. In this case the difference in temperature and barometric pressure at Chicago might account for a little more than 8 per cent of the variation.

Maximum product of wheel No. 2 at different dates.

Velocity of wind per hour.	Product at maximum.	Date.	Velocity of wind per hour.	Product at maximum.	Date.
Miles.		1883.	*Miles.*		1883.
8.485	58.083—	Apr. 10	8.478	62.928—	Apr. 27
8.499	62.719+	Apr. 11	8.496	65.474=	May 5
8.487	62.966—	Apr. 12	8.459	62.928=	May 3
8.463	62.225	Apr. 16	8.464	61.180=	May 7
8.461	58.957—	Apr. 17	8.476	62.396=	May 8
8.432	62.966+	Apr. 9	8.512	63.650=	May 1
8.432	60.762	Apr. 6	8.477	60.952	May 9
8.455	61.902—	Apr. 6	8.452	58.273	Sept. 15
8.398	61.142	Apr. 4	11.041	135.498	May 17
8.395	61.370+	Apr. 3	11.054	126.984	July 2
8.403	62.463—	Mar. 14	11.021	137.346	May 29
8.410	61.845—	Mar. 27	10.997	138.897	May 22
8.427	62.478+	Mar. 28	10.980	135.201	June 25
8.419	61.864—	Mar. 30	11.000	129.195	June 20
8.446	61.408+	Mar. 31	10.980	132.264	June 26
8.501	61.655+	Apr. 18	10.935	132.033	June 28
8.488	63.802	Apr. 28	10.994	127.116	June 29
8.500	62.852—	Apr. 26	10.975	124.839	July 5
8.425	63.726—	Apr. 25			

INFLUENCE OF OUTSIDE WIND.

Experiments were conducted in a closed room to insure the exclusion of all natural wind. The exclusion of wind from the inclosed space, however, was not perfect. The wind circling around the outside of the building undoubtedly at times caused a slight circulation of air inside, which may have been more potent in causing variations in results than either thermometric or barometric influences. The windows were always kept carefully closed during experiments, and the doors also were guarded as much as possible. The doors, however, were necessarily used, and we distinctly remember being obliged to discard many measurements on account of doors being opened during tests on windy days. But unless a door was opened during a test we considered that errors from influence of outside wind were sufficiently guarded against by our practice of comparing all results with those obtained with wheel No. 2, under like conditions, as explained in the original records.

STANDARD OF COMPARISON.

As stated in the original record, wheel No. 2, which we always used as a standard for comparison, was modeled after the Halliday 10-foot wind wheel; that is to say, the slats, arms, etc., were the same in number

and of the same relative dimensions on a scale of one-half. There was, however, this difference, that the Halliday was what is called a section wheel, having pivoted sections for the purpose of regulation. Wheel No. 2 had all its parts rigidly fixed with reference to each other, and therefore was more like the solid wheels in common use at the time. The solid wheels were really copies of the Halliday, so far as the sails or slats and the arms were concerned. The only essential difference between section and solid wind wheels related to the method of stopping and governing their motion. Different makers of both styles of wheels had their own notions about angles of weather and proportions of sail surface. The Halliday 10-foot wheel had its slats set at an angle of 35° with the plane of motion. The slats were as thin as was consistent with safety, considering that their material was wood, and they were trimmed to a sharp edge, so as to cut the air as much as possible.

Nearly all wind wheels in use at the time of our experiments in 1882–83 were made with narrow wooden slats, similar in general appearance to our wheel No. 2. Some makers adopted greater angles of weather than 35 degrees, and even let the sails overlap so as to boast of greater sail area for their wheels as a basis for claiming greater power. A 45-degree angle of weather was not uncommon, and the slats were often made thicker than those of the Halliday wheel; besides, they were not always trimmed to an edge in front.

In adopting as our standard of comparison a wheel modeled after the 10-foot Halliday, we believe that we made use of the best model available to represent wind wheels in general as then constructed.

CORRECTIONS FOR AXLE FRICTION.

In the earlier tables 0.3 pound was added to all applied loads. This 0.3 pound was arrived at as explained after the table on page 38, and was in reality an estimate of frictional resistance to starting, or to slow motion. As authorities stated that friction was the same at all velocities, we adopted 0.3 pound as approximately representing the frictional resistance of the journals without regard to speed. We afterwards learned that the axial friction diminished greatly with increase of speed of revolution, as is made evident by comparing the speeds of the same wheels after starting friction was greatly reduced with the speeds before reduction of friction under the same applied loads and also unloaded. (See original records after table on page 38.)

Wheels Nos. 2, 18, and 19, especially, may be compared. Subtract 0.3 from loads in the tables giving average results for wheels Nos. 2, 18, and 19, on pages 29, 43, and 44, and subtract 0.1 in tables on pages 27 and 47 to obtain applied loads. Evidently there is very little difference between the axial frictions in the two cases for unloaded wheels.

We can not now, after a lapse of more than fifteen years, undertake to assert what the axial friction previous to March 13, 1883, should have been called for different speeds. But if in the table on page 29 we

call friction 0.15 pound, we shall find the maximum product to be 61.846 instead of 66.860, as there recorded. And as this correction would make this table agree substantially with the general results of the table on page 74, it seems probable that 0.15 pound is about the right amount to allow for friction in the first twenty-one tables to obtain maximum products.

If in the table on page 43 for wheel No. 18 we call friction 0.15 pound, the maximum product will become 76.869, obtained January 13, 1883. On April 10, 1883, the same wheel, No. 18, gave as maximum product 69.300, showing a variation of more than 12 per cent. But the United States Signal Service records in Chicago show for these two dates a difference of more than 1 inch in the barometric column, and about 39 degrees difference in temperature, which will account for a variation of about 12 per cent. Again, if in the table on page 44 for wheel No. 19 we call friction 0.15 pound, the maximum product will become 82.130, obtained January 18, 1883. On April 11, 1883, the same wheel, No. 19, gave as maximum product 75.185, showing a variation of over 9 per cent. The differences in temperature and barometric pressure as given for these two dates by the Signal Service records at Chicago would account for a variation in atmospheric density of just about 9 per cent. These three wheels, Nos. 2, 18, and 19, are the only ones tested both before and after the reduction of friction on March 13, 1883. While the products as recorded in the tables in which 0.3 pound was added to loads are all too large, their comparative values are not greatly distorted by the excessive allowance for axial friction.

The smaller allowance for axial friction will sometimes make the maximum product correspond to the next greater applied load, as in the case of wheel No. 19, page 44. But in the tables on pages 29 and 43, after allowing 0.15 pound instead of 0.3 pound for friction, the maximum products still correspond to the same applied loads and the same speeds of revolution as before.

AERIAL FRICTION.

So far we have not attempted to estimate the friction and resistances of the air itself, although the tables on pages 57, 59, and 61 are very suggestive on this point, and theoretical considerations also indicate the great importance of this subject, as will hereafter appear.

RELATION BETWEEN SPEED AND LOAD.

The following table shows the relation between speed and load for various wind wheels:

Table showing the relation between speed and load.

No. of wheel.	Angles of weather.	A	B	$\frac{A}{B}$	C	D	$\frac{C}{D}$	Sail surface.
	°	Turns per minute at maximum.	Turns per minute unloaded.		Load at maximum.	Starting force.		*Square feet.*
1	35	31.69	59.08	.54	1.65	2.55	.65	9.19
2	35	33.43	57.95	.58	1.85	3.55	.52	18.38
3	24.5, 11.25	47.48	90.48	.52	1.35	2.10	.64	13.59
4	20, 30	55.93	89.43	.63	1.55	3.00	.52	13.59
5	22.5, 32.5	46.10	86.78	.53	1.95	3.4	.57	13.59
6	30	42.10	69.03	.61	1.65	3.1	.53	10.688
7	25	47.40	73.60	.64	1.35	2.5	.54	10.688
8	35	36.84	62.67	.59	1.75	3.25	.54	10.688
9	32.5	34.58	66.40	.52	1.95	3.1	.63	10.688
10	27.5	39.33	72.23	.54	1.75	2.95	.59	10.688
11	20	45.46	77.60	.59	1.35	2.00	.68	10.688
12	15	43.88	75.60	.58	1.15	1.4	.82	10.688
13	40	28.70	56.33	.51	2.15	3.4	.63	10.688
14	45	24.72	48.60	.51	2.15	3.5	.61	10.688
15	47.5	25.30	46.84	.54	1.95	3.65	.53	10.688
16	50	20.67	42.40	.49	2.15	3.60	.60	10.688
17	25, 35	38.70	73.90	.52	1.75	2.75	.64	10.688
18	25	39.42	75.58	.52	1.95	3.1	.63	12.937
19	27.5	38.20	72.26	.529	2.15	3.3	.65	12.937
20	30	39.87	70.78	.56	1.9	3.45	.55	12.937
21	32.5	38.72	67.97	.57	1.9	3.6	.53	12.937
22	35	31.96	64.20	.50	2.1	3.8	.55	12.937
23	25, 30	43.21	73.46	.59	1.75	3.25	.54	12.937
24	27.5	38.87	72.60	.54	1.8	3.4	.53	15.000
25	30	38.95	69.00	.56	1.8	3.6	.50	15.000
26	25	43.74	75.38	.58	1.7	3.15	.54	15.000
27	35	33.74	63.65	.53	2.1	4.0	.53	15.000
28	32.5	34.49	67.07	.51	2.1	3.8	.55	15.000
29	27.5	39.10	73.10	.53	1.9	3.6	.53	17.016
30	30	35.15	69.18	.57	2.1	3.9	.54	17.016
31	32.5	34.94	66.73	.52	2.1	4.0	.52	17.016
32	35	33.43	62.90	.53	2.1	4.2	.50	17.016
33	25	37.80	75.46	.50	1.9	3.4	.56	17.016
34	25, 35	43.77	76.47	.57	1.7	3.4	.50	12.937
35	27.5	46.64	76.78	.61	1.7	3.3	.52	12.937
36	25	47.05	80.67	.58	1.7	3.0	.57	12.937
37	30	40.41	73.12	.55	1.9	3.5	.54	12.937
38	22.5	52.51	84.65	.62	1.5	2.8	.54	12.937
39	27.5	35.57	64.52	.55	1.9	3.6	.53	13.072

Table showing the relation between speed and load—Continued.

No. of wheel.	Angles of weather.	A Turns per minute at maximum.	B Turns per minute unloaded.	$\frac{A}{B}$	C Load at maximum.	D Starting force.	$\frac{C}{D}$	Sail surface.
	°							*Square feet.*
40	27.5	45.74	82.13	.56	1.9	3.65	.52	12.937
41	25	46.81	84.70	.55	1.9	3.35	.53	12.937
42	30	43.15	77.95	.55	1.9	3.8	.50	12.937
43	25, 30	45.92	84.92	.54	1.9	3.5	.54	12.937
44	25, 30	44.35	84.88	.52	1.9	3.5	.54	13.590
45	20, 30	79.99	156.63	.51	2.9	5.1	.57	14.159
46	17.5, 27.5	85.19	160.90	.52	2.7	4.7	.57	14.159
47	22.5, 32.5	73.31	148.68	.49	3.3	5.9	.56	14.159
48	25, 35	66.79	141.97	.47	3.7	6.4	.58	14.159
49	27.5, 37.5	58.82	136.30	.43	3.9	6.5	.60	14.159

BEST SPEEDS FOR WIND WHEELS.

In the fifth column of the preceding table the decimal fractions $\frac{A}{B}$ indicate for the various wind wheels the ratio of speeds at maximum work to the speed of wheels unloaded.

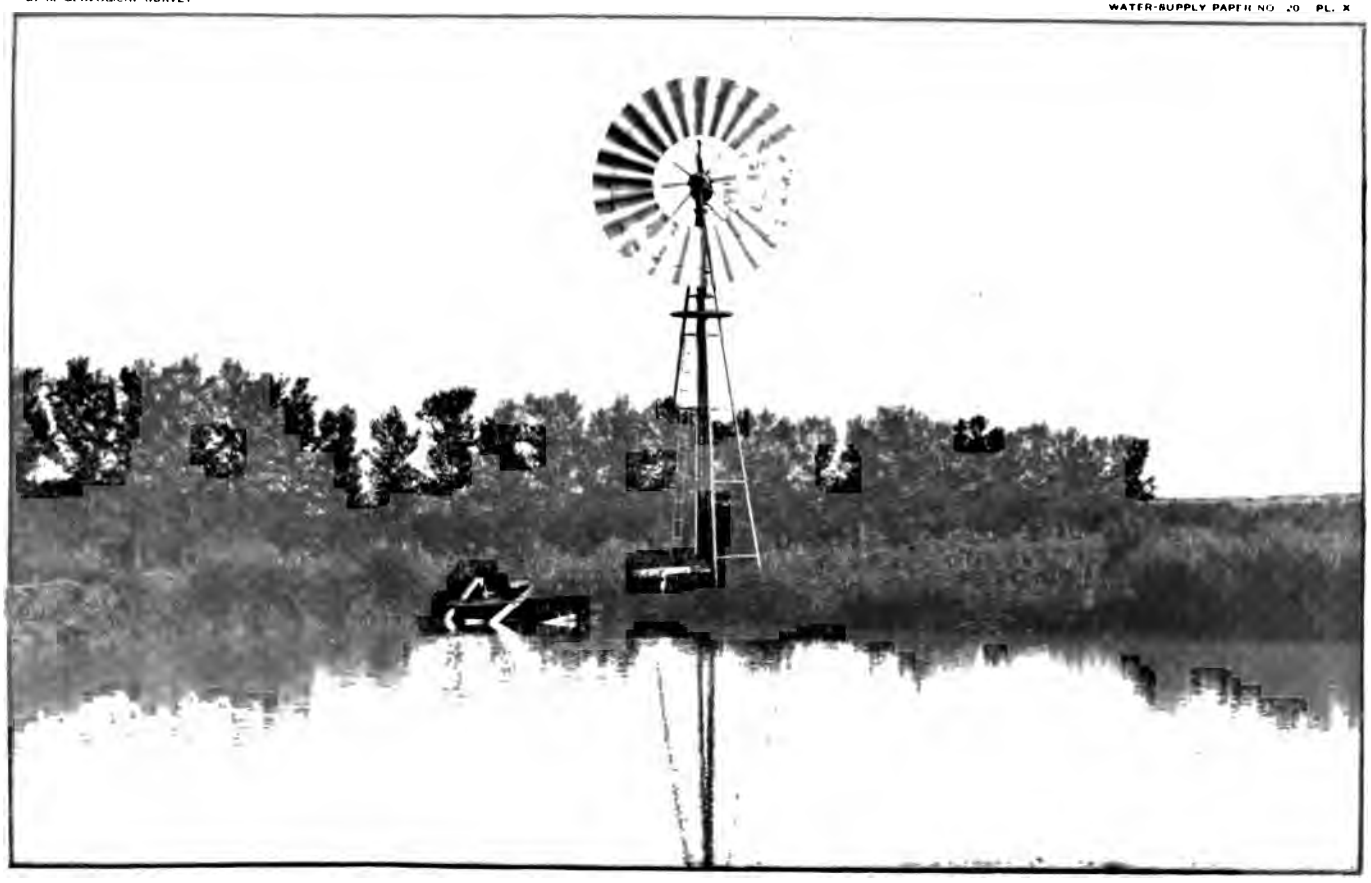
By consulting the original tables on pages 28 to 46, it may be noticed that there are generally four or five products nearly as great as the maximum product for each wheel. Where the two greatest products are nearly the same, a very slight difference in velocity of wind, or other cause, may make the maximum result correspond to either of two different loads or two different speeds. This may account for certain apparently rather wide variations in the columns $\frac{A}{B}$ and $\frac{C}{D}$.

In general the best speed for most of these wind wheels is about 0.55 of the unloaded speed, and a variation of speed between 0.45 and 0.70 of the unloaded speed will not make a very great difference in the amount of work performed, provided the load is varied to suit the difference in speed.

BEST LOADS FOR WIND WHEELS.

In the eighth column of the preceding table the decimal fractions $\frac{C}{D}$ indicate the ratios of loads at the maximum of work to the greatest loads that the wheels can start without continuous turning.

In collecting from the original tables the numbers D, which represent starting forces, the original figures were corrected so as to exclude what was originally added for axial friction. (See "Starting forces" on page 25.) Where 0.3 pound was added to applied loads prior to March 13, 1883, the figures were corrected for C in the sixth column



WINDMILL AND RESERVOIR.

to correspond to an axial friction of 0.15 pound, as explained under the heading "Corrections for axial friction," page 75.

In general, it may be said that the ratio of best loads to starting forces is about 0.55, and that there may be a variation in the load between 0.50 and 0.65 of the starting force without serious impairment of efficiency.

CONICAL DEFLECTOR IN CENTER OF WHEELS.

Wheel No. 50 was tested because our attention was called to a windmill patent in which a conical deflector was shown. Besides saving the wind that otherwise would pass through the center of wheel unoccupied by sails, an advantage was also claimed because the air was made to act with greater leverage on account of encountering the sails farther from the axis. The experiment showed there could be no possible advantage from such an arrangement.

AIR-CUSHIONED SAIL SURFACES.

When wheel No. 39 was constructed, the narrow strips of board along the edges of the sails were intended not to obstruct the spaces between sails, but to afford air cushions on the faces of the sails against which the wind might act to better advantage than against plain surfaces. It had become apparent that plain sails were decidedly inferior to sails with concave faces, whether circular or angular. (Note experiments with wheels Nos. 40, 43, and 44.)

It was contended by certain windmill experts that the narrow strips added to plain sails, as used in wheel No. 39, would answer the same purpose as the sail forms of wheels Nos. 40, 43, and 44, and that wooden wheels could be more easily constructed in that way. One of the experts had constructed wind wheels similar to wheel 39. It was immediately due to the suggestion of another prominent windmill official that wheel No. 39 was made and tested. For ourselves, we had much more decided opinions after the test than before, notwithstanding the fact that our mathematical solutions as presented in this paper were written out and made public before any of our experiments were commenced. Whatever value there may have been in the air-cushioned sail faces of wheel No. 39, the advantage was more than nullified by the obstruction of spaces between sails and the bad contours of their backs.

OBSTRUCTIONS ON THE BACK OF SAILS.

Our experience with wheel No. 39 suggested that the arms and bands also might be detrimental to the proper smooth and peaceful flow of air between the sails. So we next constructed and tested wheels Nos. 45 to 49, which have no bands and no arms along the backs of the sails. The results, as shown in the table on page 59, speak for themselves.

It may be noticed that wheel No. 47 carried 3.3 pounds as best load, the same as the best load of wheel No. 2, over which it shows a gain in power of about 83 per cent. The gain, therefore, in this case was

entirely in speed. Notice also the ratio between the speeds of the two wheels running unloaded, $\frac{148.68}{77.85}=1.91$. The denominator, 77.85, is taken from the table on page 27.

WASTE OF POWER DUE TO THE ARMS OF WIND WHEELS.

Two or three months after making the many experiments the summary of which is recorded on page 59, it occurred to us that it would be interesting to know and easy to ascertain something definite as to the gain in power effected by the removal of those portions of the arms which usually are made to extend along the backs of sails or between the sails of wind wheels. To represent the portions of arms previously removed, we prepared six pieces of pine wood 1 by 1¼ by 17 inches. These could be quickly attached to the backs of the pasteboard sails by two little screws in each, and as quickly removed, as often as necessary.

We found, on retesting wheel No. 48 in September, that it showed a gain over wheel No. 2 of 84 per cent instead of the 87 per cent gained when tested in June. We attributed this small loss to the drying and warping of the sails, and therefore designated the retested wheel as No. 60. The same wheel, with the six pine strips above mentioned fastened to the backs of the six sails, was designated as wheel No. 61. We found by repeated trials, as usual, that wheel No. 60 required, for the wind velocity taken to produce a maximum product, a load of 1.9 pounds.

This load was the same as the best load for wheel No. 2. The coincidence of best loads made the comparison of wheels No. 60 and No. 2 merely a matter of recording speeds. No time had to be consumed in changing loads and readjustments of the brake, and the two wheels were replaced by each other alternately in rapid succession.

The same method was pursued in comparing wheel No. 60 with wheel No. 61, except that in this case, instead of removing from the axle and replacing the entire wheels, we merely placed and removed in succession the six strips of pine. The table on page 61 gives the averages of results.

It is possible that 1.9 pounds may not have been exactly the best load for wheel No. 61. To facilitate the speed comparisons and render mistakes of brake adjustment impossible, the load was not changed and the adjustment of the brake was left undisturbed during these alternate tests of the two wheels. We consider it altogether probable that an exact determination and application of the best load for wheel No. 61 would not have materially changed the product as recorded. At any rate, simply removing the six strips of pine from the backs of the sails caused an increase in the speed of the wheel with the same load, from 38.13 to 56.50 turns per minute, or 48 per cent.

TWISTED SAILS.

That the angle of weather of a sail should be greatest at the end nearest the axle and least at its outer end where its speed is comparatively great, seems self-evident, and the advantages to be gained by warping or twisting the sails so as to make the weather angles increase as they approach the center have always been recognized, at least in theory, by windmill manufacturers, although comparatively few American wind wheels are made with such sails. Our best results, as shown in the table on page 59, were obtained with warped sails, but it does not appear from previous experiments that the warping was by any means the most important feature of our best wheels.

The tables on pages 51 and 53 afford, in the comparisons of wheels Nos. 34 and 43, having twisted sails, with wheels as nearly like them as possible without twisted sails, an apparent test of the advantages gained by making the weather angles greater at the inner ends of the sails. Judged by these two wheels the advantage is very slight.

We are now satisfied that merely twisting the sails can not do much good for the reason that what is gained in this way by better disposition of the forward or receiving edges of the sails is largely lost by the consequent less advantageous disposition of the rear edges from which the wind escapes.

As we have pointed out in the discussion of the theory of the windmill, the rear edge of a sail should be nearly parallel to the plane of motion without regard to radial distance, while the forward edge should be parallel to the relative direction of the impinging current of air, which depends on radial distance.

This theoretical disposition would make the angles of weather greatest where the sail speed is least, but is a very different thing from the twisting of the sails, as in wheels Nos. 34 and 43.

Fig. 26, on page 61, shows a sail form more nearly in accord with our theory, which makes not only the angle of weather, but also the curvature of the sail, greater with nearer approach to the center of the wheel.

DEFLECTORS IN FRONT OF SAILS.

In our discussion of the theory of the windmill on pages 71 and 72 we have called attention to the fact that our formula (E) indicates that the efficiency of a wind wheel might be increased if the air currents, just before meeting the sails, should be deflected so as to meet the plane of motion at a less angle than 90 degrees. In order to test somewhat this mathematical suggestion, the experiments recorded in the table on page 64 were made. Only a single deflector was used, and that a plane surface. It may be noticed that when placed in front of wheel No. 2 at various angles the deflector caused some increase of speed in every instance, while the load remained the same. But when placed in front of wheel No. 49 its effect as an obstruction overbalanced its value as a deflector.

It did not appear that deflectors would be advantageous in front of the most efficient wheel, nor of sufficient value in connection with the wheel of relatively low efficiency to justify the expense of such cumbersome appliances. We did not, therefore, consider it worth while to experiment further with deflectors.

OBSTRUCTIONS IN FRONT AND IN THE REAR OF WIND WHEELS.

The experiments recorded on page 65 we were prompted to make on account of the contention by certain windmill experts, that an obstruction behind a wind wheel caused about the same loss of power as if placed in front.

Many so-called vaneless windmills had their supporting masts, or tower tops, in front of the wheels, while the ordinary mills with vanes had their supporting masts behind the wheels.

The obstructing boards described under the table on page 65 were intended to represent such obstructions as would be representative of supporting masts placed as indicated. In the case of wheel No. 2, unloaded, the obstruction when placed in front caused a loss of speed amounting to a little more than 3.5 per cent, and when placed behind the loss amounted to a little over 3 per cent.

In the case of wheel No. 49, loaded, the loss of speed from placing the obstruction in front amounted to nearly 14 per cent, and the loss of speed from placing the obstruction behind was nearly 7 per cent.

It may be observed that 3.5 pounds is less than the best load for wheel No. 49 (3.9 pounds), but it should be borne in mind that with all wheels a considerable variation in the load made but little difference with the product when near the maximum.

It might have been profitable if we had extended these experiments. It is evident that obstructions even when relegated to the rear are not obliterated.

MAXIMUM PRODUCTS IN DIFFERENT VELOCITIES OF WIND.

The table on page 66 indicates that maximum products vary as the cubes of the velocities of wind almost as exactly in fact as in theory. If there had been an exact correspondence between the results of experiment and the law of cubes, the figures under $\left(\frac{b}{a}\right)^3$ would exactly equal those opposite under $\frac{B}{A}$. The figures under $\frac{B}{A}$ are in some instances a little greater and sometimes a little less than those opposite under $\left(\frac{b}{a}\right)^3$, as indicated by the plus and minus signs before the differences given under $\frac{B}{A} - \left(\frac{b}{a}\right)^3$. The plus and minus signs happen to be equal in number, showing a remarkable general agreement with the law of cubes. Again, the law of cubes would require that the

numbers under A multiplied by $\left(\frac{b}{a}\right)^3$ should equal the corresponding numbers under B. How nearly the law was actually fulfilled may be seen by comparing the last computed column, $A \times \left(\frac{b}{a}\right)^3$, with the real products of column B.

STARTING FORCES AND LOADS AT THE MAXIMUM IN DIFFERENT VELOCITIES OF WIND.

Under the second table on page 66 we find the conclusion that "starting forces vary as the squares of the velocities of wind." If the law of squares had been strictly confirmed, the computed ratios under $\left(\frac{b}{a}\right)^2$ would have just equaled the actual ratios of experiment as given under $\frac{B}{A}$. The agreement is quite close, but the numbers in column $\frac{B}{A}$ are more often greater than the corresponding numbers in column $\left(\frac{b}{a}\right)^2$. So it appears that starting forces really increase in at least as great a ratio as would conform to the law of squares. But, as we have explained before, it should be remembered that what we have called starting forces could neither be defined nor determined with the same accuracy as was attainable in the case of maximum products. Nor could the loads corresponding to maximum products be determined so accurately as the maximum products themselves, since two or three different loads would generally give about the same product when the product was near the maximum. This fact made it all the more easy to ascertain the maximum products correctly, since a little variation from the best load was compensated for by the consequent variation in the speed of the wheel.

The table on page 77 shows, on the whole, a fairly constant ratio between loads at the maximum and starting forces, from which we may draw the conclusion that loads at the maximum vary as the squares of the velocities of wind.

SPEEDS OF UNLOADED WHEELS IN DIFFERENT VELOCITIES OF WIND.

In the table on page 67 an inspection of columns $\frac{b}{a}$ and $\frac{B}{A}$ will show that in every case but two the counted turns of the unloaded wheel in the higher wind exceeds somewhat the number of turns computed on the supposition that the speed of an unloaded wheel should vary directly as the velocity of wind. The two exceptional cases may be accounted for. We attribute this variation from the natural law in part to the fact, previously discussed, that the axial friction diminishes as the speed increases. Strictly speaking, the wheels, on account of unavoidable friction at the axle, could not be entirely unloaded.

ACTION OF AIR ON THE SAILS OF A WIND WHEEL.

In fig. 31, AB, AB are supposed to represent cross sections of two sails, one following the other as in a wind wheel. DE represents the direction and velocity of the wind with respect to the earth. AE represents the direction and velocity of the sail sections, at right angles to DE. Then DA represents the relative direction of wind with respect to the sails in motion, and the front faces AA of the sails are set parallel to DA. The rear faces of the sails B are set parallel to the plane of the wheel's motion, according to correct theory.

As one sail necessarily follows another in a wind wheel, the air can

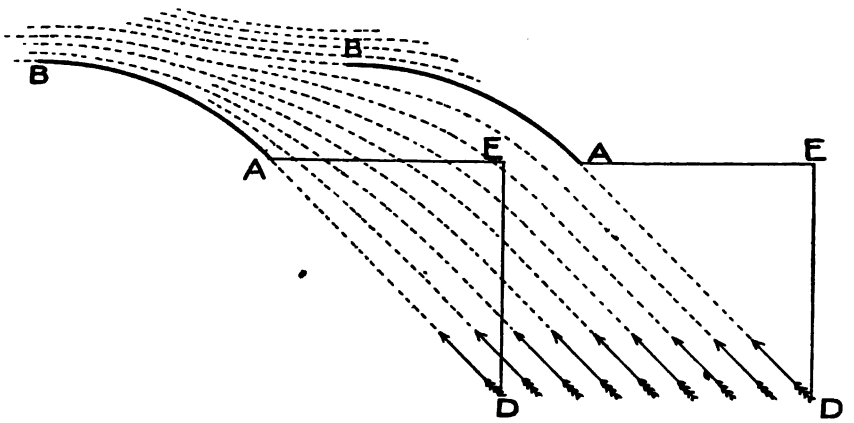


FIG 31.—Action of air on the sails of a wind wheel.

not escape in a direction exactly opposite to the sail's motion, and as the space between sails unavoidably contracts toward the rear edges these edges may in practice conform in some measure to the best possible direction of escape instead of being strictly parallel to the plane of the wheel. The placing of arms on the backs of or between the sails would render a necessary evil worse on account of further contraction of space. Besides, it should be noted that the backs of the sails, as well as their faces, play an important part in deflecting the wind. For it is a well-known fact that air currents cling to and follow the surfaces along which they flow. Therefore, the backs of the sails should be smooth and free from obstructions. It is evident that all the air passing between the sails is deflected and not merely that portion which comes immediately in contact with the faces of the sails. The arrows and dotted lines in the figure indicate the relative direction and deflection of air as it flows through the wheel.

THEORETICAL EFFICIENCY OF THE WIND WHEEL.

Our general formulæ and deductions previously given under theory of the windmill are presented just as they were originally recorded near the beginning of the year 1882. We now see no reason for alter-

ing them in any respect, but there has been so much confusion among mathematical writers on wind action, that we wish to make the matter perfectly clear in its essential points.

It is not necessary to resort to the calculus, nor even to produce the general formulæ (A) and (B) in order to arrive at the theoretical efficiency of a wind wheel. A very simple, graphical solution may be shown as follows: In figs. 32 to 35, AB represents the direction and velocity of the wind with respect to the earth; AC represents the direction and velocity of the sail, a section of which is represented by the curved line CD; the velocity of wind AB is the same for each of the four cases; and the several sail sections are supposed to be taken at the extremity of a sail in fig. 32, at a distance from the center of the wheel equal to two-thirds the radius in fig. 33, at one-third the radial distance in fig. 34, and at one-sixth in fig. 35. We have assumed that

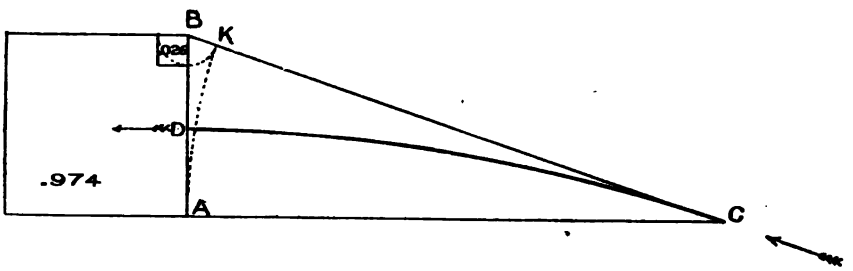


Fig. 32.

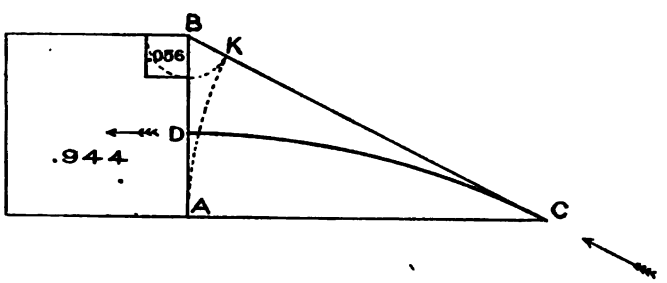


Fig. 33.

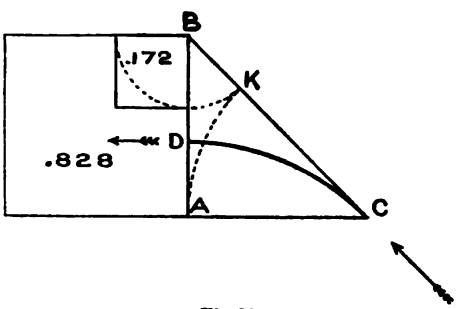


Fig. 34.

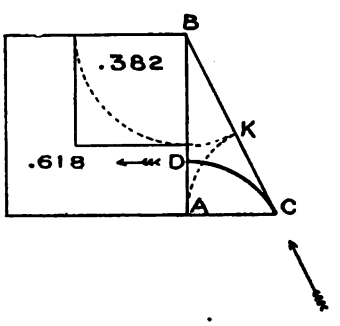


Fig. 35.

FIGS. 32-35.—Theoretical efficiency of the windmill.

the outer extremity of the sail travels three times as fast as the wind. That is to say,

$$AC = 3 \times AB \text{ in fig. 32,}$$

$$AC = 2 \times AB \text{ in fig. 33,}$$

$$AC = 1 \times AB \text{ in fig. 34,}$$

$$AC = \tfrac{1}{2} \times AB \text{ in fig. 35.}$$

CB represents the relative direction and velocity of the wind with respect to the sail in each case. Neglecting friction, the relative velocity of the wind is not changed by contact with the sail. The air escapes from the sail at D with the same relative velocity it had at C; but its course is changed so that it escapes in a direction parallel and opposite to that of the sail's motion. Now, since the sail is traveling with an actual velocity AC in one direction while the air is escaping with a relative velocity CB in the opposite direction, the difference between CB and AC = BK will represent the actual velocity of the air after it has escaped from the sail. The remnant of velocity BK is all there is left of the wind's original motion. The sail has absorbed the rest and converted into work a corresponding amount of energy. A certain quantity of wind started with a velocity AB and gave up all its energy except that corresponding to a velocity BK.

Now, the potential energy of the same quantity of air in motion varies as the square of its velocity, as in the case of any other substance. Hence a square constructed on AB and another square constructed on BK will represent relatively the original potential energy of the wind and the energy it still retains after encountering the sail. These squares are shown in the figures. The small squares represent the waste of energy or that not consumed by the sail. The relative areas of these squares may be readily computed. Taking the large squares as unity the small square equals 0.026 in fig. 32, 0.056 in fig. 33, 0.172 in fig. 34, and 0.382 in fig. 35. The efficiency is represented by the difference between the squares; thus, the efficiency in fig. 32 is 0.974; in fig. 33, 0.944; in fig. 34, 0.828, and in fig. 35, 0.618.

The small squares correspond to the letter k in the formula (B) on page 71. Compare these efficiencies with the values of $1-k$ as originally obtained by a very different process. There would have been no difference if the decimals had been equally carried out in both cases.

The potential energy of the wind, as well as the useful work resulting from its action on a sail, varies as the cube of its velocity, because the quantity of air coming in contact with the sail increases or diminishes with the change of velocity in the same proportion. It is only when we consider the result of a fixed quantity of air in motion, that its energy varies as the square of velocity and may be represented by square areas as illustrated above.

The work of the same quantity of air varies as the square of velocity, because its resultant reaction against the sail varies directly as the velocity and the sail also travels with the same proportional velocity. If, for instance, 1 pound of air, acting on a sail, has its velocity doubled, the sail travels with double velocity under doubled pressure, so that the work is increased fourfold; and, as in reality the doubling of velocity would cause 2 pounds of natural wind to meet the sail in the same time, the result is doubled again, making it eightfold in theory as well as in practice.

THEORETICAL USEFUL EFFORT OF WIND.

In the figs. 36 to 39, let AB represent the direction and velocity of wind with respect to the earth. In fig. 36 let AC = 3 AB represent the direction and velocity of the outer extremity of a wind wheel; in fig. 37 at two-thirds of the radius from center, AC = 2 AB; in fig. 38 at one-third the radius from center, AC = AB, and in fig. 39 at one-sixth the radius, AC = ½ AB. The circular arc CD in each figure represents correctly what the cross section of the sail at each point should be according to theory. To make the calculation simple and specific, we will consider the action of 1 pound of air only, and that moving at an original velocity of 32.2 feet per second.

We take this particular velocity because it requires the constant action of a 1-pound force to give to 1 pound of air, or to 1 pound of any substance, a velocity of 32.2 feet per second.

To give other velocities to the 1 pound of air, requires the impelling action of a force proportional to the velocity imparted in a second of time. That is to say, the force required to impart to 1 pound of air any velocity, v, is represented in pounds by $\frac{v}{32.2}$.

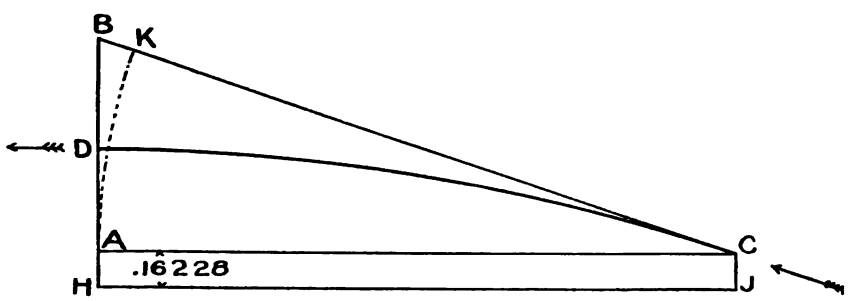


Fig. 36.

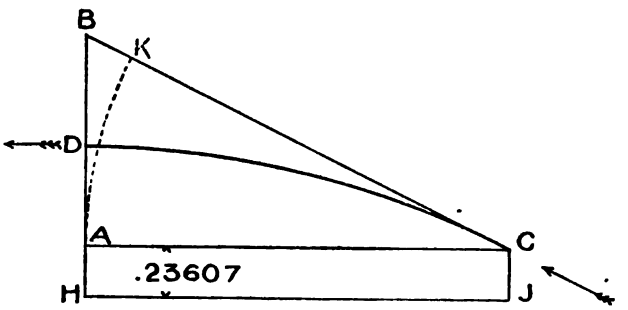


Fig. 37.

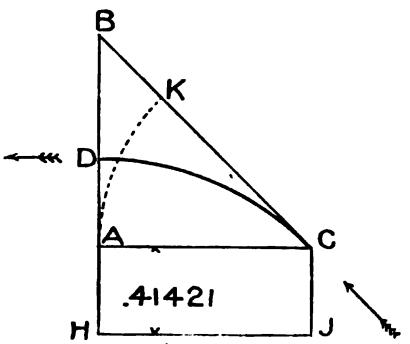


Fig. 38.

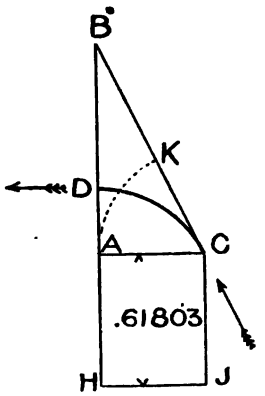


Fig. 39.

FIGS. 36-39.—Theoretical useful effort of wind.

The sail of a wind wheel moves at right angles to the direction of wind or in the direction AC, but the wind meets the sail in motion in the relative direction and with the relative velocity CB, and has with reference to the sail, due to the sail's motion, an opposite motion equal to CA in the direction C to A in addition to its original motion. The length of the line CB represents the velocity with which the air flows along the surface of the sail with undiminished relative velocity, neglecting friction, and the difference between CB and CA, or BK, represents the relative velocity acquired in a second by the air in a direction parallel to CA. That is to say, by action against the sail during one second, the 1 pound of air has acquired a relative velocity BK in a direction parallel to CA, in addition to the relative velocity CA which it had before meeting the sail. This newly acquired relative velocity BK required for its generation a force reacting between the sail and the air proportional to the acceleration of velocity. If BK were equal to 32.2 feet, the reaction would be 1 pound. But the reaction is less than 1 pound in the same ratio that BK is less than AB, which we assumed to be 32.2 feet.

AB:BK:: 1 pound: Useful effort of wind.

So $\frac{BK}{AB}$ represents the ratio between original wind pressure in the

WINDMILL AND RESERVOIR.

direction of its original motion and the useful effort which pushes the sail in the direction of its motion. If we lay off on BA prolonged AH=BK and complete the rectangles ACJH, the areas of these rectangles in figs. 36 to 39, will represent relatively the work theoretically performed in each case. The effort AH may be readily computed. For the action of 1 pound of air, at velocity of 32.2 feet per second, we find that the useful effort is 0.162 pound when the sail moves 3 times as fast as the wind, 0.236 pound when the sail moves twice as fast as the wind, 0.414 pound when the sail moves as fast as the wind, and 0.618 pound when the sail moves one-half as fast as the wind.

AERIAL RESISTANCE TO MOTION.

It should be noted that by far the most striking and important results of our experiments with wind wheels were produced by cutting out from between the sails obstructions which produced aerial resistance to motion; and it should be profitable to study the causes which make these aerial obstructions apparently a matter of greater moment than all the other features of our investigation.

In the two preceding articles we have shown that the greater the sail velocities, theoretically the higher the efficiencies, and also that the useful efforts become smaller as the sail velocities increase.

When the sail travels three times as fast as the wind, the theoretical efficiency is 0.974, very close to perfection; but for a wind velocity of 32.2 feet per second, each pound of air gives a useful effort of only 0.162 pound. It is evident at once that while high sail velocity seems desirable, it does not require great aerial resistance to counteract a large percentage of the useful effort. When the sail travels three times as fast as the wind, a flat resisting surface of about 1 square inch set perpendicular to the direction of motion would counteract entirely the useful effort due to the action of 1 pound of air. This is computed as follows:

At a velocity of 32.2 feet per second, 1 pound of air per second under ordinary conditions represents a stream of about 59 square inches area in cross section; from which it follows that 59 square inches of flat surface carried normally against still air at the rate of 32.2 feet per second meets with a resistance equal to 1 pound, and at a velocity three times as great meets with a resistance of 9 pounds. But the total useful effort in this case is only 0.162 pound.

Therefore we obtain $F=\frac{59\times 0.162}{9}=1.062$ square inches = flat resisting surface required completely to neutralize all useful effort of wind whose normal pressure against 59 square inches of flat surface equals 1 pound. In like manner we find that F equals 3.418 square inches where the sail velocity is twice the wind velocity, 24.426 square inches where the sail velocity equals the wind velocity, and 145.848 square inches where the sail velocity is one-half the wind velocity.

If we let f be the percentage of wind area represented by F, we find that $f=0.018$ when sail velocity is three times wind velocity, 0.059 when sail velocity is twice the wind velocity, 0.414 when sail velocity is equal to wind velocity, and 2.472 when sail velocity is one-half wind velocity.

These percentages hold good for all velocities of wind and emphasize the necessity of reducing to the utmost aerial resistances to motion, if we are to attain high efficiency in a wind wheel.

BEST NUMBER OF SAILS.

An inspection of the table on page 65 shows that wheel No. 35 was more than 3 per cent better than wheel No. 19, although the amounts of sail surface and the angles of weather were the same in both. Wheel No. 35 had exactly the same sails as No. 19, except that each sail of No. 35 contained two of No. 19 placed edge to edge, making 12 broad sails instead of 24 narrow ones. By simply changing the angle of weather from 27.5 degrees to 25 degrees, we made No. 35 into No. 36 and thus gained nearly 6 per cent over No. 19. The wide sails did better with less angle of weather. Wheel No. 6, with the same number of sails as No. 19 but narrower, required a greater angle of weather, 30 degrees.

It is apparent that for a given total of sail area it is better to divide the surface between fewer sails. It may be noted that wheel No. 48, with six sails, gave, in proportion to total sail area, nearly two and a half times the efficiency of No. 2 with 60 sails. Reducing the number of sails reduces the aerial resistance to motion due to the number of edges, and leaves relatively freer interstices for the flow of air between the sails.

BEST RELATIVE AREAS OF SAIL SURFACE.

Tables on pages 47 and 49 give the following results for wheels Nos. 19, 24, and 29:

Effect of area of sail surface on efficiency.

	No. 19.	No. 24.	No. 29.
Square feet of sail surface	12.937	15.000	17.016
Ratio of maximum products (*a*)	1.204	1.212	1.201

a Compared with wheel No. 2.

These three wheels were nearly of the same efficiency. As compared with the area of the zone containing the sails, No. 19 was about three-fourths full, No. 24 was about seven-eighths full, and No. 29 was what we call full, as the total area of the sails about equaled the area of the zone containing them. These wheels all contained the same number of sails set at the same angle, and differed only in width of the sails. It is clear that nothing was gained by making the total sail area more than seven-eighths of the zone, and that very little was

gained by filling beyond three fourths of the zone—surely not enough to pay for the extra material.

From the table on page 65 we obtain the relative values for three wheels per square foot of sail surface, viz, for No. 19, 0.0[illegible] should No. 24, 0.0808; and for No. 29, 0.0706. Notice also the relative machine per square foot of sail surface as given for other wheels in this table as

ACTUAL EFFICIENCY OF THE WIND WHEEL.

To obtain the actual efficiency of wind wheel No. 2, taking the result recorded in the table on page 27, we first obtain the maximum work performed by multiplying the maximum product by the circumference of a circle whose diameter is 2 feet. (See note under the table on page 28.)

62.463 = maximum product in the table.

6.283 feet = circumference of circle 2 feet in diameter.

62.463 × 6.283 = 392.455 foot-pounds per minute = work of wind wheel No. 2 at maximum.

The potential energy of the wind is expressed by the well-known formula $\frac{W v^2}{2 g} = \frac{W}{32.2} \times \frac{v^2}{2}$ in which we make W = weight of air intercepted per second by the total area of the wind wheel. v = velocity of wind in feet per second, and $g = 32.2$, the velocity acquired each second by a body whose motion is not resisted when impelled by a constant force equal to its own weight. The temperature as recorded was 50° F., and on the same day at 2 p. m., in Chicago, the barometer stood at 28.983. Hence 0.075 pound may be taken as the weight of 1 cubic foot of air, 19.635 square feet as the total area of the wheel which was 5 feet in diameter, and 12.286 feet per second, or 8.403 miles per hour, as the velocity of wind. Thus, $W = 19.635 \times 12.286 \times 0.075$ = 18.093 pounds per second, $v^2 = 150.946$, and $\frac{W v^2}{2 g} = \frac{18.093 \times 150.946}{2 \times 32.2}$ = 42.4078 foot-pounds per second, or 2544.468 foot-pounds per minute. The portion of actual energy of wind utilized by wind wheel No. 2, or its efficiency, is accordingly $\frac{392.455}{2544.468} = 0.154+$.

To obtain the efficiency of any other wind wheel whose maximum product is directly compared with maximum product of wheel No. 2 as shown in the tables of later date than March 13, 1883, it is only necessary to multiply 0.154, the efficiency of wheel No. 2, by the ratio of products obtainable from the various tables.

For example, in the table on page 59 we find 1.872 given as the ratio of maximum products for wheels No. 48 and No. 2. Hence, 0.154 × 1.872 = 0.288 is the efficiency of wheel No. 48. This is the highest efficiency attained by any of the wheels whose products are recorded in the preceding tables.

WORK OF VARIABLE WIND WITH VARIABLE LOAD.

In most localities the velocity of the wind is exceedingly variable. The average of velocity recorded for an hour by an anemometer gives no idea of the total actual energy of the wind.

The wind might in conception be actually of uniform velocity, but where the average velocity is 10 miles per hour it is quite as likely to blow one-half the time at the rate of 20 miles and during the other half not at all. The potential energy of 20-mile wind for half an hour is four times as great as that of a uniform 10-mile wind for a whole hour, although the average velocity per hour in each case is the same.

This is taking an extreme case, but it shows how the wind as it blows may and does develop much more energy than could be derived from uniform wind of equal velocity as usually recorded. It would be desirable, if possible, to have the load applied to a wind wheel vary as the square of the velocity of wind, in order that the work might be the greatest possible. Any fixed load which allows the wheel to run freely most of the time is generally altogether too small during much of the time as well as too great at other times. For most uses to which wind wheels are especially adapted an automatic regulation of the load to meet the varying wind would make the best form of wind wheel regulation.

REGULATION OF WIND WHEELS.

Ordinarily wind wheels in this country are made to regulate themselves automatically, so that they can not attain a very rapid rate of rotation. This practice of not allowing the wheel to run at more than a very moderate speed is due to the fact that our wind wheels have been developed mostly in connection with the operation of common reciprocating pumps attached directly to a crank on the shaft of the wheel. Such direct connection necessitates a slow motion of the wheel, in order that the piston speed of the pump may not exceed its economical limit. The consequence is that many wind wheels are allowed to do only a small part of the work which they are capable of developing. Too much attention has been paid to restraining automatically the speed of wind wheels by means which involve a waste of power. So far as the safety of the wheel itself is concerned there should be no need of restraining its speed in any wind under 40 miles per hour; and it should be borne in mind that strains on the wheel, due to any given amount of work, may be diminished in the same ratio that the speed of the wheel is increased.

The gearing of a wind wheel, whether it is geared up or down, should be made to suit the work and the nature of the device through which the power of the wheel is applied to use. When the machine driven requires a high speed of revolution, much gearing up may be avoided if the wind wheel is allowed to revolve rapidly. Back gearing for slow running machines should be resorted to whenever a direct connection

with the machine to be driven will not allow the driven mechanism and the wind wheel both to have their best speeds with reference to work and wind.

For any given velocity of wind the speed of the wind wheel should not change, no matter what the nature of the work or of the machine through which work is performed; but the gearing should be such as to suit the load to the wind.

LIMITATION TO SIZE OF WIND WHEELS ON ACCOUNT OF WEIGHT.

Probably in no other form of motor does a gain in efficiency effect so great a saving in weight as in the wind wheel. The strength of other motors needs to be proportional to their own power. A 4-horsepower steam engine for instance does not need to weigh more than four times as much as a 1-horsepower engine, as the strains to which it is subjected are only four times as great. But a 4-horsepower wind wheel needs to be eight times as heavy as a 1-horsepower wheel in order to resist equally well the violence of exceptional storms. It is the strains of storms, and not its own working strains, that determine the required strength of a wind wheel.

Consider a single sail A supported on the end of an arm fastened to a central spider. Let L = length of the arm from center of wind pressure on sail to point of attachment to spider. If the wind wheel is doubled in diameter, keeping the same proportions, L will be doubled and the area of A will be four times as great. Hence the arm needs to resist four times the wind pressure acting at double the former distance out from its point of attachment, and needs to have eight times its former strength. This eightfold strength is secured by doubling all lineal dimensions, as evidently should be done, when the diameter of a wind wheel is doubled.

But the doubling of all lineal dimensions makes the wheel weigh eight times as much, and as its area is only four times as great, it follows that, in proportion to its power, the weight of the wheel is doubled.

As actually made, all the dimensions of large wind mills do not conform strictly to the proportions of small mills, and often the large wheels are built after different models from small ones. But it is well-known that the large wheels as built do not resist storms so well as small ones, and costly experience has taught manufacturers to make the weight of their large wheels at least approximately what calculation requires.

On account of the disproportionate weight of large wind wheels, the towers which support them also have to be made considerably heavier than would be the case if the large wheels required no more material in proportion to power than do small wheels. If the tower for a large wind wheel were of correspondingly greater height, the weights of towers would follow the same law that should control the weights of wheels.

It is evident that small wind wheels are more efficient in proportion

to weight than large ones, and that the cost of construction, as the wheels are made larger, is increased in much greater proportion than the gain in power.

EFFICIENCY OF WIND WHEELS AS AFFECTED BY DIAMETER.

Another reason why small wind wheels are more efficient than large ones is that the wind meets all parts of the area of a small wheel with greater uniformity of velocity. It needs no special acuteness of observation to discover that the wind strikes different portions of large wheels with great unevenness of velocity.

Before commencing the experiments here recorded we attempted to measure the power of a wind wheel 22 feet in diameter in natural wind. By way of preparation we made a special anemometer, which indicated at sight the velocity of wind. We placed the anemometer as near to the wind wheel as possible, expecting to be able to note where its pointer stood and know the wind velocity for a minute of time, during which the revolutions of the wheel carrying a known load might be counted. The first thing we learned was that the anemometer never pointed steadily to any uniform velocity of wind even for one-fourth of a minute, and we next observed that the anemometer would sometimes almost stop running when the wind wheel showed an extra spurt of speed; also the wind wheel would slow down while the speed of the anemometer was accelerated. We could often hear the wind whistling through the sails on the opposite side of the wind wheel, while very little wind was felt on the near side close to the anemometer. We were unable to obtain a single measurement which we considered worth preservation. We could not determine even the best load for any wind, to say nothing about comparative results. We do not doubt that localities might be found where the wind would blow with greater uniformity, but our experience in trying to measure the power of wind wheels in natural wind led us to provide for artificial wind before proceeding further. The slight variations in the best artificial wind we could command caused a great abundance of vexations, which made the obtaining of accurate average results a matter of tedious labor.

HEIGHT OF TOWERS.

Nothing like steady wind can be obtained near the ground in an inhabited country. Buildings, trees, and other obstructions set the wind to whirling and cause it to flow in sinuous streams of very uneven velocity, concentrated in one place at the expense of another.

There is no effective remedy except in the elevation of the wind wheels several feet at least above all obstructions, even if the obstructions are isolated and a thousand feet away. In order that a large wind wheel may be as efficient in proportion to its area as a small wheel, its height above the ground must be greater. So it is probably not far out of the way to say that the weights of the towers as well as

WINDMILL ON LOW TOWER ON THE GREAT PLAINS.

Casc

the weights of the wind wheels, for equal safety and efficiency, should be nearly proportional to the cubes of the diameters of the wheels.

MULTIPLICATION OF WIND POWER.

We have shown that for equal safety in storms the weights of wind wheels of different sizes and like forms should be proportioned to the cubes of their diameters. It would require four 12-foot wheels to equal the area and power of one 24-foot wheel, if the larger wheel is proportionately elevated. But the weight of the one 24-foot wheel would be twice as great as the combined weight of the four 12-foot wheels, and the weight of the one higher tower would probably be twice that of the four shorter towers combined. Hence it would seem that in proportion to the power obtained in each case, the one 24-foot wheel would cost twice as much in material. The thought naturally presents itself that the four 12-foot wheels ought in some way to be combined so as to act in unison for concentrating a great amount of power where it is desirable to use the power at only one point, as in driving one machine of large dimensions. If the four wheels were coupled together rigidly the trouble from uneven reception of wind which is experienced in large wheels would be augmented. The problem has not been worked out, but we may imagine a number of wind wheels, each compressing air according to its own ability and delivering it at any distance into a common reservoir. Natural elevations would be selected as locations for windmills, and such a plant could not be rendered useless for the time by an accident to one or two of the wind wheels. There would necessarily be considerable loss in compressing air, but a low-pressure system might be devised that would greatly reduce the waste. Some waste of power attends every mode of transmission. In seeking to make a gain in power of 100 per cent in proportion to cost of plant, the loss of an extra 25 per cent in transmission might well be tolerated.

There may, however, be other and better methods for accomplishing the object in view than by the means we have ventured to suggest.

POWER OF TWELVE-FOOT WIND WHEEL.

The maximum product of our best experimental wheel, No. 48, is given as 247.123 in the table on page 59, and the velocity of wind as 10.935 miles per hour.

The constant 6.283 multiplied by products gives the foot-pounds of work per minute. Hence $247.123 \times 6.283 = 1552.674$ foot-pounds = work per minute of No. 48 in wind of 10.935 miles per hour.

The work of 5-mile wind compared with the work of 10.935-mile wind is $\left(\frac{5}{10.935}\right)^3$ or .0956. Hence, the work of No. 48 is, in 5-mile wind, $1552.674 \times .0956$ or 148.345 foot-pounds. The work of a 12-foot wheel in 5-mile wind is $148.345 \times \left(\frac{12}{5}\right)^2$ or 854.467 foot-pounds, which is equal to 0.0259 horsepower.

It is, therefore, approximately correct to call the power of a 12-foot wind wheel in 5-mile wind equal to one-fortieth of a horsepower. Computing the power of other wind velocities according to the law of cubes, we obtain for the power of a 12-foot wheel, one-fortieth or 0.025 horsepower in 5-mile wind, 0.2 horsepower in 10-mile wind, 0.675 horsepower in 15-mile wind, 1.6 horsepower in 20-mile wind, 3.125 horsepower in 25-mile wind, 5.4 horsepower in 30-mile wind, 8.575 horsepower in 35-mile wind, and 12.8 horsepower in 40-mile wind.

Most 12-foot wind wheels, as now made, are strong enough to stand the strain of furnishing 13-horsepower, and this we believe is not beyond the actual achievement of some 12-foot wind wheels in 40-mile wind.

VALUE OF MATHEMATICAL FORMULÆ IN EXPERIMENTAL INVESTIGATIONS.

The formulæ which Professor Rankine and other mathematicians have applied to wind wheels give for maximum theoretical efficiency only 50 per cent of the potential energy of the wind actually intercepted by the sails. Our experimental wind wheel No. 48 realized an efficiency of more than 44 per cent, if we consider only the wind which would be intercepted by a surface equal to the projections of the sails on the plane of the wheel. So, if we should accept previous mathematical calculations as correct, we have already made a wind wheel which utilizes 88 per cent of the greatest possible theoretical result, and the remaining 12 per cent margin would not furnish very great incentive to attempts at improvement. Mathematicians hitherto have treated the sails of wind wheels as flat surfaces. Even for flat surfaces their theoretical results have been entirely too small; but it is not our purpose to discuss previous mathematical errors. Wind-wheel sails of proper form are not flat, but curved surfaces, and in analyzing the action of wind on curved sails we have not contradicted Rankine's formulæ, but have confined ourselves to making such suppositions as may be actually true in practice. Rankine's formulæ for the action of fluids on curved vanes give as a theoretical result a maximum efficiency of 100 per cent. This is correct. It shows that we have not made a very efficient wind wheel yet, and affords hope for the attainment of still better results in the future. We know that there is a great waste of energy somewhere, even in the best wind wheels we have been able to produce, but we are encouraged to think that much of the waste can be avoided. We do not claim, therefore, that our experiments have revealed the whole truth. In fact we believe that only a beginning has been made, and fully expect to see our best results greatly surpassed. In our view, the results of our experiments, as here recorded, are far richer in the suggestions offered than in the efficiencies realized.

INDEX.

Page.

Air, resistance of..... 71, 76, 80, 89
Air currents, action of..... 84
Air-cushioned sails, description of..... 57, 79
American wind wheels, development of.... 19, 30, 74, 75, 92
Anemometer, description of..... 94
Angle of impingement, theory of..... 70, 71, 72
Angle of weather, experiments with.... 22, 75, 90
  Theory of..... 72
Barometric influences, effect of..... 27, 72, 76
Brake, automatic adjustment of..... 27, 67, 68, 69
  Description of..... 23, 24, 67
Deflector, experiments with..... 46, 64, 79, 81
  Theory of..... 71
Dynamometer, description of..... 23
Efficiency of windmills, determination of... 22, 60, 91, 96
  Effect of area of sails on..... 90-91
  Effect of diameter of wheel on..... 94
  Theory of..... 69-72, 84-87
Energy of wind. (*See* Wind.)
Experiments with windmills, methods of... 24, 25, 26, 27, 42
  Place of..... 9, 21, 22, 72, 73
Friction, corrections for..... 25, 26, 38, 75-76
Friction brake. (*See* Brake.)
Gearing of windmills, method of..... 92-93
Journals, friction of..... 25-26
Loads of windmills, application of..... 23-24
  Axle friction included in..... 24, 75
  Determination of best..... 77-79, 83
  Law of squares for..... 66, 83
  Regulation of variable..... 92
Newell, F. H., introduction by..... 11-18
  Letter of transmittal by..... 9
Obstructing edges, effect of..... 90
Obstructions before and behind wheels, effect of..... 65, 82
Obstructions on sails, effect of.... 57, 61, 62, 79, 89
Power of wind wheel, determination of.... 95
Products, determination of maximum..... 24, 27, 42, 73, 76. 82-83
  Effect of journal friction on..... 20, 22, 24, 25, 26, 75, 76
  Effect of state of atmosphere on.... 27, 72, 76

Page.

Regulation of wind wheels, methods of..... 92-93
Results of experiments, variations in 73
Sail area, determination of best..... 65, 90-91
Sails, angle of weather of..... 22, 41, 42, 51, 52, 90
  Effect of twisting of 51, 53, 57, 81
  Efficiency of..... 85
  Forms of..... 65, 69, 72, 84, 85, 90
  Inclination of. (*See* Angle of weather.)
  Number of..... 28, 29, 65, 90
  Obstructions on. (*See* Obstructions.)
  Speed of..... 59, 71, 89, 93
Smeaton, John, experiments of..... 19, 20, 21
Speed indicators, forms of 23, 24, 42
Speed of wind wheels, determination of.... 25, 67, 77, 78, 83, 93
Starting forces, best angles for..... 40, 41
  Definition and measurement of. 25, 66, 77-79, 83
Thermometric influences, effect of..... 27, 72, 76
Towers, height and weight of..... 93-94
Wind, effect of circular motion on 20, 21, 23
  Efficiency and waste of..... 85
  Energy of..... 69, 86, 91, 92, 95
  Escaping currents of..... 69, 71, 72
  Experiments in natural 92, 94
  Impinging currents of 60, 70, 72
  Theory of the action of 69, 72, 84
  Use of artificial 21, 22, 42, 74
  Useful effort of..... 87-89
Wind wheels, determination of power of .. 95
  Determination of speed of...25, 67, 77, 78, 83, 93
  Dimensions of..... 93-94
  Effect of obstructions on..... 28, 29, 60, 64, 80
  Efficiency of. (*See* Efficiency.)
  Forms of..... 19, 20, 30, 74, 75
  Methods of regulation of..... 92-93
  Reversal of 34, 43
  Sail area for..... 90
  Size of 93, 94
  Towers for..... 93-95
Work of wind wheels, computation of... 24, 91, 95
  Graphic representations of..... 87, 88
  In variable winds..... 92
  Law of cubes for 66, 82, 86
  Strains due to..... 92
  Theoretical formula for 69, 70

55TH CONGRESS, 3d Session. } HOUSE OF REPRESENTATIVES. { DOCUMENT No. 278.

DEPARTMENT OF THE INTERIOR

WATER-SUPPLY

AND

IRRIGATION PAPERS

OF THE

UNITED STATES GEOLOGICAL SURVEY

No. 21

WELLS OF NORTHERN INDIANA.—LEVERETT

WASHINGTON
GOVERNMENT PRINTING OFFICE
1899

UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

WELLS OF NORTHERN INDIANA

BY

FRANK LEVERETT

WASHINGTON
GOVERNMENT PRINTING OFFICE
1899

ILLUSTRATIONS.

PLATE I. Map of Indiana showing the relation of the drift to the ordinary wells 9
II. Map of Indiana showing the Pleistocene deposits 12

LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF HYDROGRAPHY,
Washington, October 20, 1898.

SIR: I have the honor to transmit herewith a report on the wells of Indiana, prepared by Mr. Frank Leverett, assistant geologist of this Survey. This material was brought together by Mr. Leverett in connection with glacial investigations, as noted in the general discussion of the water resources of Indiana and Ohio, published in Part IV of the Eighteenth Annual Report of the Survey, on pages 419–559. Many details were omitted in that publication, as the volume assumed bulky dimensions; but these detailed facts have considerable value and are needed for reference by citizens of Indiana, and it is therefore desirable to make them available by publishing them in the series of Water-Supply and Irrigation Papers.

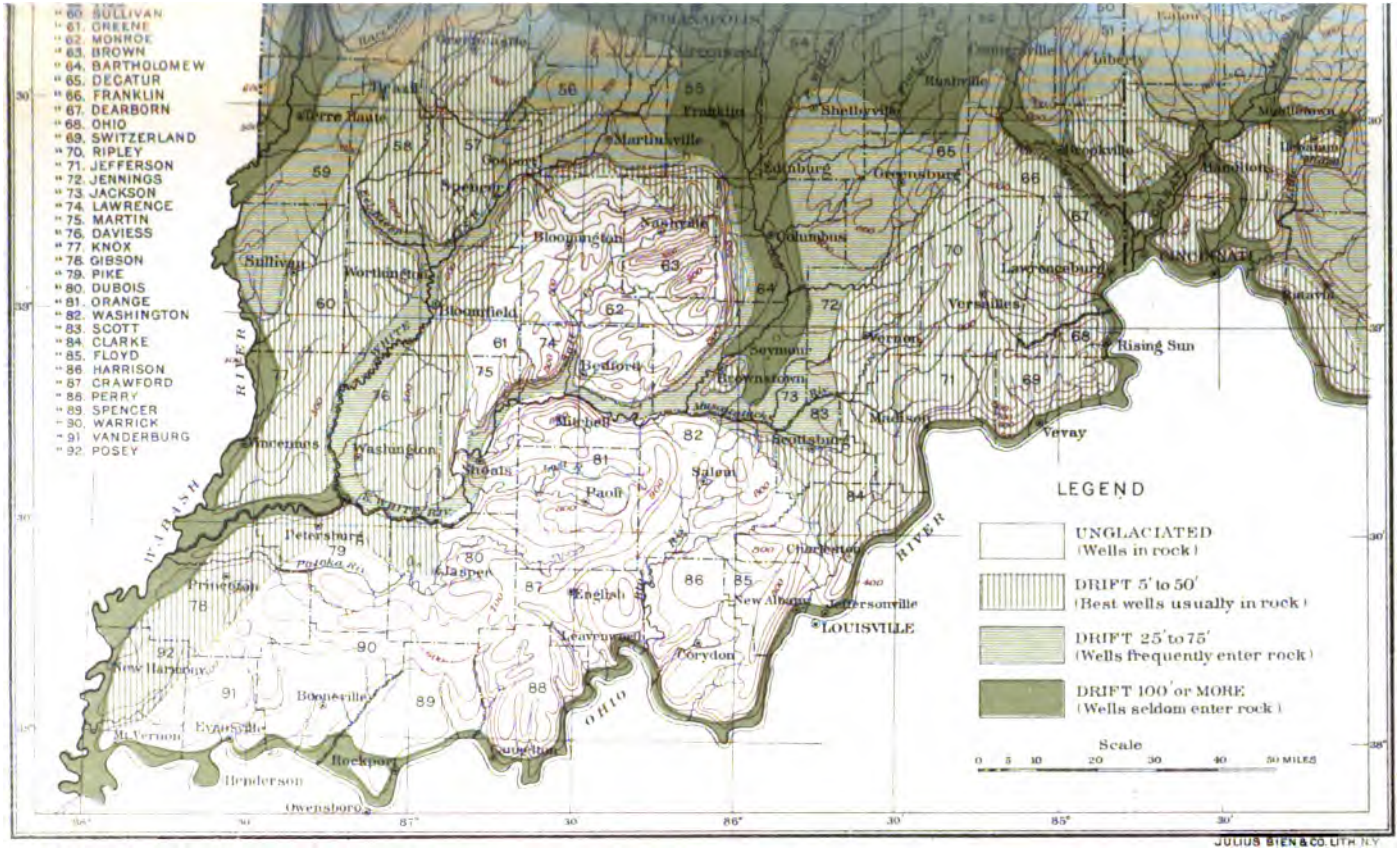
With these data are presented two maps, one illustrating the distribution of the glacial deposits and the other the relation of the drift to the ordinary wells of the State. These are portions of Plates XXXVI and XXXVII of Part IV of the Eighteenth Annual Report. Their reproduction in connection with this paper is essential to the clear understanding of the descriptive matter.

Very respectfully,

F. H. NEWELL,
Hydrographer in Charge.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

88° 30' 87° 30' 86° 30' 85° 30'
CHICAGO
LAKE MICHIGAN
COUNTIES IN INDIANA
No. 1. LAKE
" 2. PORTER
" 3. LA PORTE
" 4. ST JOSEPH
" 5. ELKHART
" 6. LAGRANGE
" 7. STEUBEN
" 8. DEKALB
" 9. NOBLE
" 10. KOSCIUSKO
" 11. MARSHALL
" 12. STARKE
" 13. NEWTON
" 14. JASPER
" 15. PULASKI
" 16. FULTON
" 17. WHITLEY
" 18. ALLEN
" 19. ADAMS
" 20. WELLS
" 21. HUNTINGTON
" 22. WABASH
" 23. MIAMI
" 24. CASS
" 25. WHITE
" 26. BENTON
" 27. WARREN
" 28. TIPPECANOE
" 29. CARROLL
" 30. CLINTON
" 31. HOWARD
" 32. TIPTON
" 33. GRANT
" 34. BLACKFORD
" 35. JAY
" 36. RANDOLPH
" 37. DELAWARE
" 38. MADISON
" 39. HAMILTON
" 40. BOONE
" 41. MONTGOMERY
" 42. FOUNTAIN
" 43. VERMILION
" 44. PARKE
" 45. PUTNAM
" 46. HENDRICKS
" 47. MARION
" 48. HANCOCK
" 49. HENRY
" 50. WAYNE
" 51. UNION
" 52. FAYETTE
" 53. RUSH
" 54. SHELBY
" 55. JOHNSON
" 56. MORGAN
" 57. OWEN
Niles
South Bend
Elkhart
Lagrange
Angola
La Porte
Goshen
Valparaiso
Crown Point
Knox
Plymouth
Warsaw
Kendallville
Auburn
Wauseon
Napoleon
Bryan
Defiance
Fort Wayne
Huntington
Wabash
Peru
Logansport
Marion
Kokomo
Hartford
Portland
Dunkirk
Muncie
Anderson
Elwood
Tipton
Frankfort
Lafayette
Attica
Covington
Crawfordsville
Rockville
Terre Haute
Greencastle
Van Wert
Lima
Celina
Wapakoneta
Sidney
Piqua
Troy
Greenville
Richmond
Newcastle
Winamac
Rensselaer
Monticello
Remington
Chalmers
Fowler
Oxford
Delphi
Flora
Williamsport
Newport
Wild Cat Creek
Tippecanoe River
Wabash River
Mississinewa River
Salamonie River
Blanchard River
Auglaize River
Big Four R.R.
Michigan Cy
Columbia Cy
Union Cy
Winchester
Ridgeville
Portland
Ogneya
Bluffton
Decatur
Ottawa
Building
Pulaski
Jasper
Newton
Benton
Warren
Fountain
Parke
Putnam
Hendricks
Marion
Hancock
Henry
Wayne
Union
Fayette
Rush
Shelby
Johnson
Morgan
Owen



MAP OF INDIANA SHOWING THE RELATION OF THE DRIFT TO THE ORDINARY WELLS

BY FRANK LEVERETT, 1897

WELLS OF NORTHERN INDIANA.[1]

By FRANK LEVERETT.

GENERAL STATEMENT.

The data included in this discussion of Indiana wells were collected mainly during the prosecution of the study of the glacial drift by the writer under the direction of Prof. T. C. Chamberlin. The portion of the State north of the latitude of Terre Haute and Brookville, embracing about two-thirds of the area, has been examined much more thoroughly than the portion south of that line. In the former district nearly every township has been traversed and close attention given to the conditions for obtaining wells. In the latter district only a few hasty trips have been made. Consequently the discussion for the northern two-thirds of the State is much fuller than for the southern third. In addition to material personally collected a considerable amount is taken from reports of the Indiana geological survey, many well sections having been published in those reports. Such material is accredited to the original sources.

A portion of the State, as has long been known, lies outside the glacial boundary. The approximate position of the boundary has been determined in part by Prof. G. F. Wright, in connection with the United States Geological Survey, and in part by members of the Indiana geological survey. Professor Wright's location of the glacial boundary in the southwestern part of the State appears to be less accurate than in the southeastern part. In the former district it has been found by members of the Indiana survey and also by Prof. J. C. Branner to be in places at least 20 miles back from the limits of the drift, but in the latter district the writer's studies have sustained, in the main, the tracing made by Professor Wright, no drift having been noted more than 6 or 8 miles outside his line. The latest results concerning the position of the glacial boundary are embodied in the glacial map of Indiana and Ohio here presented (Pl. I). It will be observed that the boundary lies south of the Ohio River as far west as the vicinity of Louisville, Kentucky. Just above this city it crosses the Ohio and turns abruptly northward, passing through western Clarke, northeastern Washington, central Jackson, and eastern Brown

[1] The length of a single paper in this series being limited by law to 100 pages, it is necessary to divide this paper into two parts and issue them separately. The last part, relating to the southern portion of the State, will be published as Water-Supply and Irrigation Paper No. 26 (in press).

counties, Indiana, a distance of about 50 miles. The course is then westward for about 30 miles, through northern Brown and northern Monroe counties. In northwestern Monroe County it makes an abrupt turn to the south and leads through western Monroe, eastern Greene, western Martin, and northwestern Dubois counties. From southwestern Dubois County the course is south of west across Pike, Gibson, and Posey counties to the extreme southwestern corner of the State.

The average thickness of the drift in the State is estimated to be about 130 feet. It consists of a complex series of sheets, differing widely in age and in structure. These sheets are made known largely by the well sections which appear in this report, for streams and natural exposures seldom reach the bottom of the drift. From a study of the drift sheets of Indiana and neighboring States, the glacial succession has been worked out sufficiently to determine the leading stages of glaciation and deglaciation.

It appears that the sheet which forms the surface of much of the glaciated portion of Illinois, and which is known as the Illinoian drift sheet, is exposed only in a few counties in Indiana, in the southwestern and southeastern portions of the State, the remainder being covered by later deposits of drift. The thickness where this single sheet is exposed to view averages scarcely more than 30 feet, or less than one-fourth the estimated average for the State.

In Illinois and Iowa there is a sheet of glacial drift exposed to view which was apparently deposited contemporaneously with the great silt deposit of the Mississippi Valley, to which the German term *loess* has been applied. This sheet has not yet been identified in Indiana, but the Illinoian drift sheet, where exposed to view, is capped by a deposit of loess-like silt, several feet in thickness, which was in all probability deposited at the time of the loess deposition of the Mississippi Valley and of the correlative drift sheet, which from its development in Iowa is known as the Iowan sheet. The Iowan drift sheet may be present underneath later drift sheets in the northern portion of Indiana.

The next important stage of glaciation has been termed the Wisconsin, chiefly because of its extent and early recognition as a later sheet of drift in the State of that name. It covers the northeastern fourth of Illinois and extends south into Indiana, about to the latitude of Terre Haute and Brookville. The border is somewhat irregular, but departs scarcely more than 20 miles to the north or south of a line leading eastward from Terre Haute to Brookville, the greatest departure being in the western part of the State, where it is deflected northward near the line of the Wabash River about 20 miles. The course of this boundary is indicated on the glacial map (Pl. I). It passes near the towns of Terre Haute, Rockville, Greencastle, Mooresville, Columbus, and Brookville. The loess referred to above covers

the drift to the south of this line, but passes beneath the drift of Wisconsin age to the north of it. In the discussion of counties near this boundary numerous sections are given showing that the Wisconsin drift is much fresher than that which underlies it. The difference in age is known not only by difference in induration of the bowlder clays, but also by the presence of a distinct soil formed on a land surface between the withdrawal of the ice of Illinoian age and the glacial advances which resulted in the deposition of later drift sheets. A soil is found between the Illinoian drift sheet and the capping of loess as well as between the latter and the overlying Wisconsin drift.

From the time the ice sheet occupied the outer border of the Wisconsin drift down to its final withdrawal from the State, it was apparently subjected to considerable oscillation of front and also to a shifting in direction of movement. In the earlier stages the movement was apparently nearly southward across northern Indiana, but in the later stages there was a change to a southwestward movement. There is a growing tendency among the glacialists who are familiar with this region to separate the two movements, giving the name Early Wisconsin to the southward and Late Wisconsin to the southwestward movement.

During the southwestward movement Indiana was covered by ice nearly as far south as during the southward movement, but Illinois was invaded to a comparatively short distance at that stage of glaciation. During this southwestward movement the ice sheet was divided into a series of lobes whose extent and characteristics have been set forth by Chamberlin in the Third Annual Report of this Survey. At the junction of these lobes great interlobate moraines were formed. One of these, occupying the line between the Saginaw and Erie-Maumee lobes, leads from the northeastern corner of Indiana southwestward to Cass County. These interlobate moraines are generally more prominent than those formed at the ends of the lobes. The one just referred to has a few knolls which rise nearly 200 feet above the neighboring basins, though the oscillations in level between knolls and basins are generally less than 50 feet. One of the most prominent moraines formed at the end of an ice lobe is the Valparaiso, situated north of the Kankakee Basin, in northwestern Indiana, and so called from the city of Valparaiso, located on it. It was formed by the Lake Michigan glacier at a time when that glacier extended but little beyond the limits of the shore of Lake Michigan. Another prominent moraine, known as the Maxinkuckee, leads southward from Michigan past South Bend to Lake Maxinkuckee, and thence eastward to join the great interlobate moraine formed between the Saginaw and Erie lobes. It was formed by the Saginaw ice lobe at the time it first became clearly differentiated from the Erie lobe. These and several other moraines are discussed in connection with the well sections which have been sunk in them. Further discussion at this point seems, therefore, unnecessary.

It will be observed that the structure of the drift is intimately related to the position with reference to the ice margin at the time of deposition. Much of the drift deposited under the margin of the ice is a compact, bowlder clay, to which the Scottish term *till* is applied, while that deposited at the end, or carried beyond the ice by waters issuing from it, consists largely of sand and gravel, or if the issuing waters were sluggish the deposits may be of a silty character.

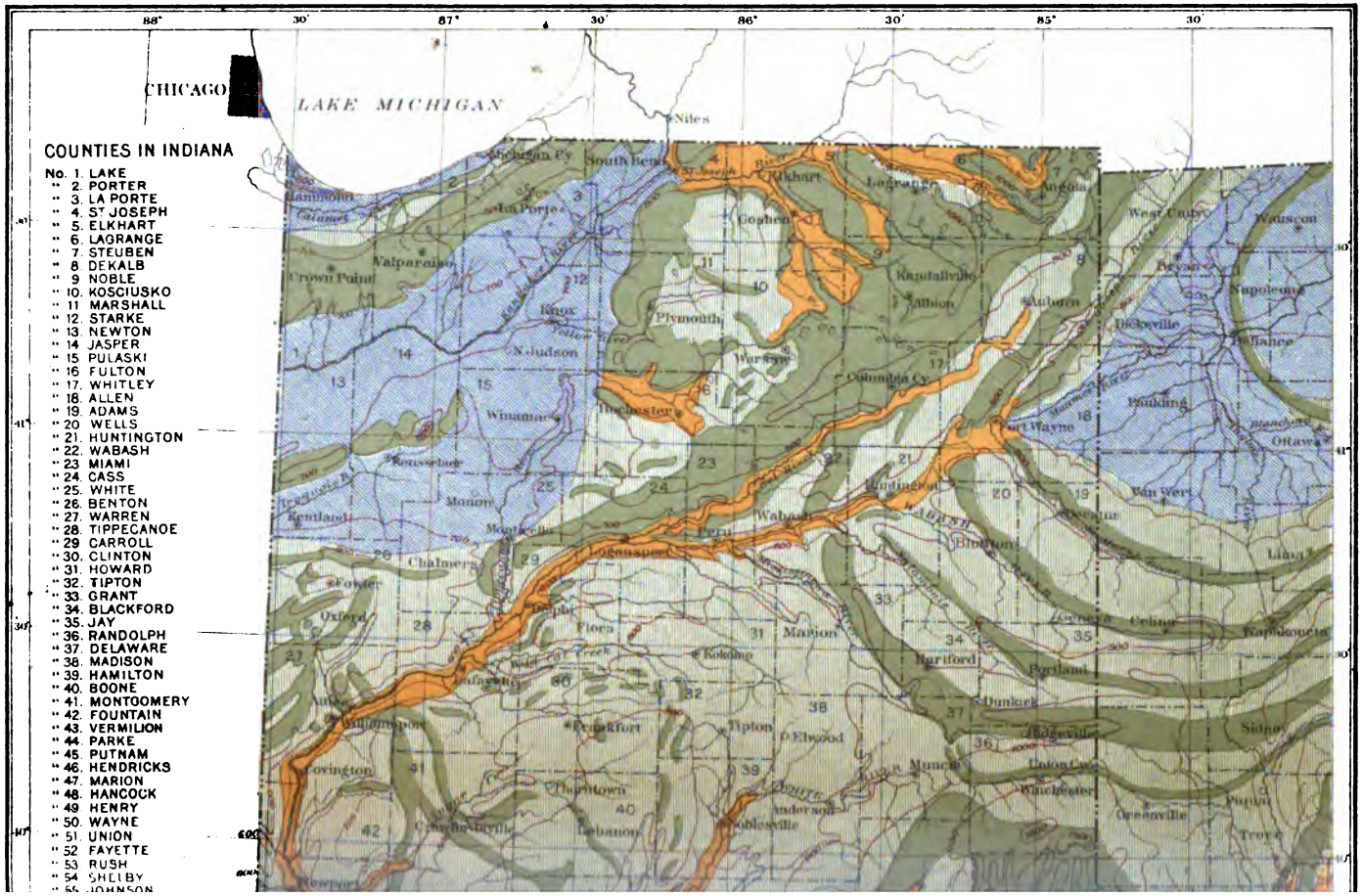
In the discussion of the counties which border the Kankakee marsh attention is called to a deposit of sand which covers the glacial drift. It was formed apparently by a glacial lake which occupied that region for a brief period while the ice sheet was still blocking the Wabash Valley to the south. This lake was long since recognized by Bradley and named Lake Kankakee.[1] A lake formerly extended beyond the present shore of Lake Michigan into the northwestern counties of Indiana, to which the writer has recently applied the name Lake Chicago.[2] It had southwestward discharge, through what is known as the Chicago outlet, into the Des Plaines River and thence to the Illinois and Mississippi. This lake also has left deposits of sand on the counties of Indiana which it covered. In the northeastern part of Indiana there is also an old lake area with well-defined beach lines, occupied by the glacial Lake Maumee,[3] which had southwestward discharge, through the "Fort Wayne outlet," into the Wabash River. This lake bottom is covered less thickly by deposits of sand and silt than the bottoms of Lakes Kankakee and Chicago.

The discussion begins at the northwestern corner of the State, and counties are taken up in order in tiers, the first tier running west to east, the second from east to west, the third from west to east, etc., following nearly the numbering of the counties on the maps. In the case of the southern counties, the data are so meager that they are considered in groups under the head of the immediately subjacent rock formation.

The records of wells here presented should not be understood to indicate the usual depth, for the majority of wells probably are less than 25 feet in depth. They represent the deepest concerning which information could be obtained, and are selected because such wells convey more information con erning the drift structure and its capacity for supplying wells than the shallow ones. The relation of the drift to the ordinary wells is set forth in Pl. II.

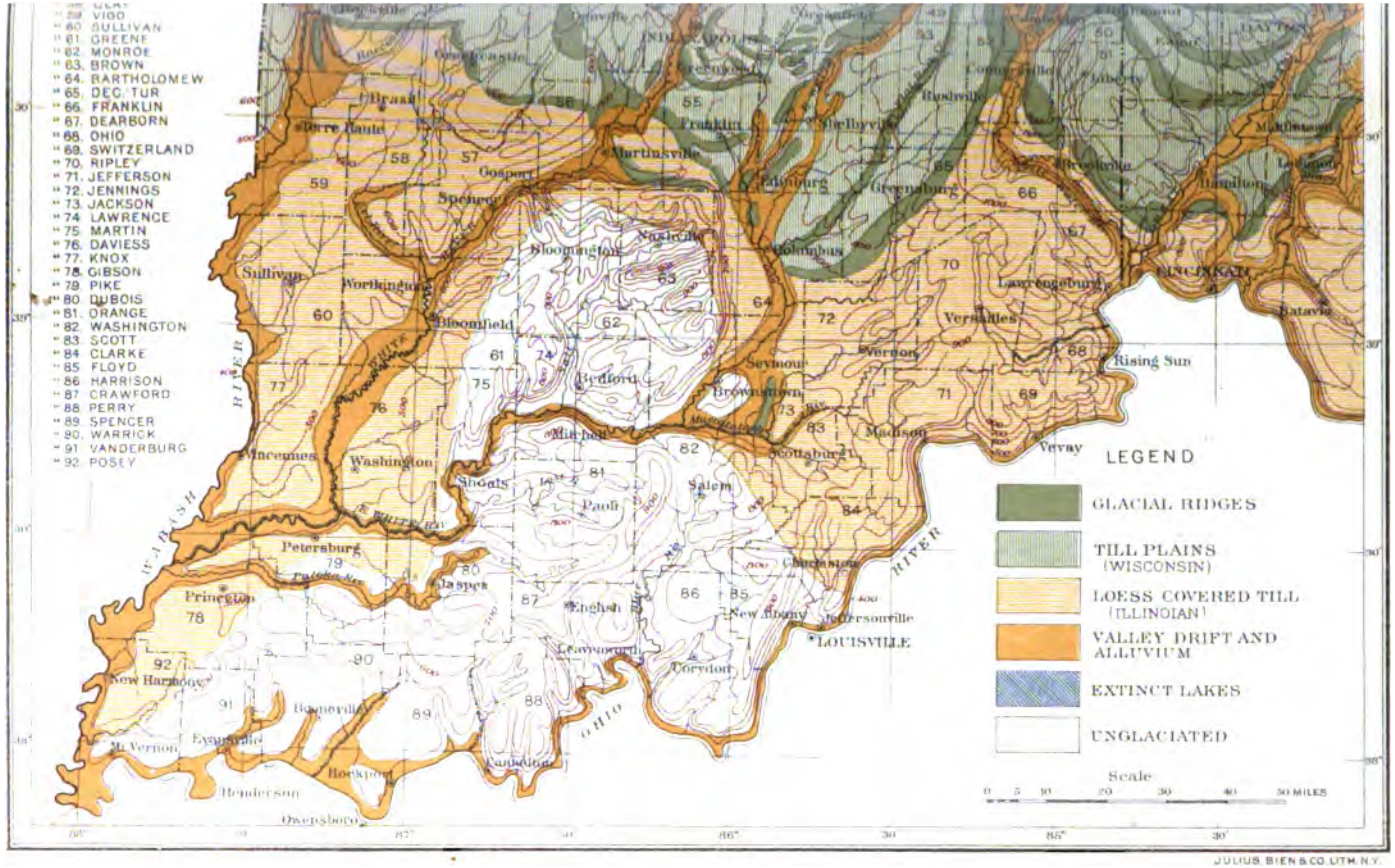
The borings for natural gas, which are especially numerous in the central and eastern parts of the State, often throw light upon the structure of the deeper portion of the drift and its water resources where deep water wells have not been made. They also throw considerable light upon the water horizons in the underlying rock strata. Such information as was obtained from the records of these borings is

[1] Geol. of Illinois, Vol. IV, 1870, pp. 226–229.
[2] Geol. and Nat. Hist. Survey, Chicago Acad. of Sciences, Bull. No. 2, 1897, pp. 64–66.
[3] C. R. Dryer, Sixteenth Ann. Rept. Indiana Geol. Survey, 1888, pp. 107–114.



COUNTIES IN INDIANA

No. 1. LAKE
" 2. PORTER
" 3. LA PORTE
" 4. ST JOSEPH
" 5. ELKHART
" 6. LAGRANGE
" 7. STEUBEN
" 8 DEKALB
" 9 NOBLE
" 10. KOSCIUSKO
" 11 MARSHALL
" 12. STARKE
" 13. NEWTON
" 14 JASPER
" 15. PULASKI
" 16 FULTON
" 17. WHITLEY
" 18. ALLEN
" 19. ADAMS
" 20 WELLS
" 21. HUNTINGTON
" 22. WABASH
" 23 MIAMI
" 24. CASS
" 25. WHITE
" 26. BENTON
" 27. WARREN
" 28. TIPPECANOE
" 29 CARROLL
" 30. CLINTON
" 31. HOWARD
" 32. TIPTON
" 33. GRANT
" 34. BLACKFORD
" 35. JAY
" 36. RANDOLPH
" 37. DELAWARE
" 38. MADISON
" 39. HAMILTON
" 40. BOONE
" 41. MONTGOMERY
" 42. FOUNTAIN
" 43. VERMILION
" 44. PARKE
" 45. PUTNAM
" 46. HENDRICKS
" 47. MARION
" 48. HANCOCK
" 49 HENRY
" 50. WAYNE
" 51. UNION
" 52 FAYETTE
" 53 RUSH
" 54 SHELBY
" 55 JOHNSON



JULIUS BIEN & CO. LITH. N.Y.

MAP OF INDIANA SHOWING THE PLEISTOCENE DEPOSITS

BY FRANK LEVERETT, 1897

here presented, though it is not so full as could be desired. In this connection it may be remarked that information concerning water supply in the deeper part of the drift and in the underlying rocks is very meager, compared with the knowledge concerning the surface portion of the drift. Information concerning these deeper beds has been greatly extended since the discovery of natural gas. In many instances borings which failed to obtain gas have been subsequently turned to use because of the water which they yield. Thus a resource which was overlooked in the excitement incident to the discovery of gas is likely to receive proper development in the near future.

DETAILED DISCUSSION OF WELLS.

LAKE COUNTY.

General statement.—Lake County, situated in the extreme northwest corner of Indiana, has for its northern border the shore of Lake Michigan and for its southern border the Kankakee River. It extends eastward from the State line about 16 miles, and has an area of 500 square miles.

The Valparaiso moraine leads west to east across the central portion of the county, and has a width of about 10 miles. It is a somewhat elevated rolling tract, standing 100 to 200 feet higher than Lake Michigan. Wells are sunk to considerable depth, few wells being obtained at less than 25 feet, while many are 50 to 100 feet or more. These wells are obtained usually in beds or pockets of sand or gravel between till sheets.

North of the moraine there is a low plain, much of which was covered by Lake Chicago, the glacial predecessor of Lake Michigan, which had its outlet southwest to the Des Plaines River. For several miles south from the present shore of Lake Michigan the sand deposits of this old lake bottom are so heavy that wells 10 to 40 feet in depth are often obtained without reaching the underlying till. But near the moraine the sand becomes thinner, and is in places but a mere skim coating. On this portion of the plain wells are carried to as great depth as on the moraine, and water is obtained in gravel deposits in the till.

South of the Valparaiso moraine is a narrow strip of gravelly land formed by the waters escaping from the ice at the time it occupied the moraine. On this plain the wells usually obtain their water at depths of 10 to 25 feet, without reaching the bottom of the gravel deposit. Extending several miles north from the Kankakee, in the southern part of the county, there is a marsh too wet for settlement.

The glacial deposits of Lake County are so heavy that wells may be obtained without entering the underlying rock. Borings for artesian water or for natural gas, made at Hammond, Hobart, and Crown Point, penetrate 110, 160, and 176 feet of drift, respectively. From these borings it appears that the drift of this county may have an average thickness of about 150 feet.

Individual wells.—At Hammond many wells are driven to a depth of 10 to 18 feet in sand, entering water at about 8 feet. Filters are used in some cases. Below the sand is a nearly solid bed of blue till, 90 feet in thickness, which contains but little water. At about 110 feet Lockport (often called Niagara) limestone is entered, which furnishes water containing sulphureted hydrogen. The artesian well boring at the distillery, 1,900 feet in depth, is discussed elsewhere.[1]

At Whiting a portion of the water supply is furnished by shallow wells in the beach sand, 20 feet or less in depth. A portion of the water supply is pumped from Lake Michigan by the Standard Oil Company and made use of by many families.

The villages of Gibson, Hessville, Tolleston, Liverpool, and Lake all depend upon shallow wells driven or dug to a depth of 10 to 40 feet in the surface sand. In some cases contamination is liable to occur from privy vaults and other sources.

At Hobart the wells 15 to 25 feet in depth usually penetrate a few feet of clay, which probably prevents contamination of water. A well at Owens's brickyard reaches the underlying rock and has the following section:

	Feet.
Yellow silt, pebbleless, calcareous	10
Blue silt, pebbleless, calcareous	50
Blue till, hard and stony	97
Hard rock	3
Total	160

Mr. Leavenworth's well, 3 miles west of Hobart, depth 80 feet, is above the limits of the lake deposit and is mainly through blue till. Several wells in that vicinity 50 to 100 feet deep do not reach the bottom of the drift.

Wells in the vicinity of Ainsworth, on the north slope of the Valparaiso moraine, often exceed 50 feet. After penetrating yellow till 10 or 12 feet they are mainly through blue till.

In the vicinity of Crown Point, near the crest of the Valparaiso moraine, there are several tubular wells 75 or 80 feet in depth, mainly through blue till.

Tubular wells in the vicinity of St. John, near the crest of the moraine, obtain water at 50 to 100 feet in sand beds included in the till.

Wells on the south slope of the Valparaiso moraine usually enter a water-bearing sand or gravel after penetrating a few feet of till, water being more easily obtained there than on the crest or north slope.

A well at the powder factory, 1 mile west of Miller Station, in the northern part of the county, 75 feet in depth, entered a bed of molluscan shells at the bottom of the sand, 40 feet below the surface and probably several feet above the level of Lake Michigan. Below the shells a bluish silt or fine sand is penetrated 35 feet.

[1] See Eighteenth Ann. Rept. U. S. Geol. Survey, 1896-97, Part IV, 1897, p. 489.

PORTER COUNTY.

General statement.—Porter County is situated just east of Lake County, and has Lake Michigan for its northern and the Kankakee River for its southern border. It is 15 miles in breadth, 25 to 30 miles in length, and has an area of 410 square miles.

The Valparaiso moraine traverses the county from southwest to northeast, slightly north of the center, and has a width of about 8 miles. It reaches a higher elevation in this county than in Lake, some points being fully 250 feet above Lake Michigan. It includes several lakes, one of which furnishes the water supply for Valparaiso, the county seat. In the western portion of the county till predominates as far as wells penetrate—150 to 200 feet. But in the eastern portion of the county, where the moraine reaches its highest elevation, it contains a large amount of dry sand and gravel, and strong wells are obtained only by penetrating to a depth of 100 to 160 reet.

Extending north from the moraine there is a low plain reaching to the Calumet River, which is underlain, as a rule, by till, but is coated quite generally with sand. In this plain wells vary greatly in depth, but are usually 20 to 40 feet.

North of the Calumet River there is a narrow ridge of till forming a feeble morainic belt. Its width seldom exceeds 1 mile and its relief is but 30 to 50 feet. Along this ridge wells are frequently 75 to 125 feet in depth, it being one of the most difficult places in the county to obtain water.

North of this till ridge there are heavy deposits of lake sand, rendering a portion of the district a barren waste. The sand is drifted by the wind into dunes 100 to 200 feet in height. This belt, however, occupies only a breadth of 2 or 3 miles, though extending the entire width of the county. This district is largely uninhabited. In the farms along its border next the till ridge wells usually obtain water before reaching the bottom of the sand at depths of 25 to 50 feet.

South of the Valparaiso moraine the formations are like those of Lake County, there being a gravel plain several miles in width, extending on the south into the uninhabited Kankakee marsh. The moraine extends spurs out into this gravel plain nearly to the borders of the marsh.

The glacial deposits of this county, like those of Lake, are so heavy that wells obtain water without entering the underlying rock. Borings for natural gas made at Valparaiso, Hebron, and Boone Grove penetrate 126, 108, and 140 feet of drift, respectively, while a boring for an artesian well in the northeast part of the county has 245 feet of drift. It appears from these borings that the average thickness of the drift in this county may slightly exceed 150 feet. Several wells along the Valparaiso moraine, as indicated below, reach a depth of over 150 feet without entering rock.

Individual wells.—The Blair artesian well, in the extreme northeast corner of the county (sec. 1, T. 37, R. 5 W.), has the following section:

	Feet.
1. Sand with peaty beds near bottom	30
2. Adhesive blue clay with thin sand beds	55
3. Gravel and sand with water	9
4. Blue clay like No. 2	110
5. Gravel with water	6
6. Blue clay like No. 2	85
7. Shale (?)	1
8. Hard gray limestone	180
9. Soft rock, subject to caving in places	66
10. Hard limestone	372
Total	864

The well mouth is about 20 feet above Lake Michigan, or 600 feet above tide. Flows occur at 68, 72, 78, 80, 85, 95, and about 200 feet in the drift. The flows were weak until a depth of about 85 feet was reached, when a strong flow with head 18 feet above the surface was obtained. The flow from 200 feet is also strong. The water from all the veins in the drift is fresh and of good quality. At a depth of 370 feet sulphur water was struck, which gradually increased in strength in the next 150 feet. The head is, however, 10 feet lower than that from the drift deposits. The combined flow is about 400 barrels per hour and the temperature 62° F.

At Furnessville, on a beach line in the north part of the county, a well 80 feet in depth penetrated beach sand 25 feet, at the base of which logs were encountered. Below the logs is a blue clay, probably till, which was penetrated about 50 feet when a water-bearing sand and gravel was struck.

A well on the beach line immediately north of Calumet River, near the east line of the county, obtains water at the base of the beach sand at 23 feet. Neighboring wells south of the beach line enter a blue clay, nearly pebbleless, at 3 to 5 feet, and in some cases penetrate this to a depth of 50 feet before obtaining water.

At Chesterton and Hageman, in the northern part of the county, wells are seldom more than 20 feet in depth, and usually obtain water at 10 or 12 feet. As they are mainly through sand, there is danger of contamination.

Records of several wells were obtained along the till ridge north of Calumet River, near Chesterton. They penetrate yellow till 18 or 20 feet, below which is a blue till, hard and stony, which is usually penetrated 40 or 50 feet before a water-bearing sand or gravel can be obtained. In one well a dry sand, 15 or 20 feet in thickness, was found between the yellow and blue tills, and the blue till there afforded no water until it had been penetrated 70 feet. The depth of the well is 125 feet.

From the Calumet River south to the Valparaiso moraine water is usually obtained at 8 to 25 feet. In some cases surface clay a few feet in depth is penetrated, but quite as often the wells are almost entirely in sand or gravel. In the western part of the county, however, in the vicinity of Wheeler and northward for 4 or 5 miles, this plain is underlain by a compact till, and wells are in some places difficult to obtain. There is a small till ridge leading north from Wheeler, on which it is especially difficult to obtain wells. Several borings have been made along the ridge to a depth of 100 to 200 feet. In one case a boring was abandoned at 200 feet without obtaining water. In another case water was obtained after penetrating 155 feet of till. Another well found water after penetrating 115 feet of till. A plain known as Twenty Mile Prairie, lying north and east of the till ridge just mentioned, is underlain by a very fine sand, so that wells have been carried to a depth of 150 feet before entering coarse sand or gravel. On this prairie there is usually:

	Feet.
1. Yellow till	7 to 10
2. Blue till	20
3. Fine gray quicksand	75 to 125

Passing to the Valparaiso moraine, we find in the western part of the county a region in which strong wells are difficult to obtain, except in a few favored localities, there being a very compact till, similar to that on the plain north of the moraine. At Smalls Crossing, 3 miles southwest of Wheeler, a well penetrates the following beds:

	Feet.
1. Yellow till	8 to 10
2. Blue till	35 to 40
3. A fine sandy deposit, in places resembling till	150
4. Coarse water-bearing sand	19
Total	219

Mr. Currier's well, 1 mile south of Wheeler, in which no good vein of water was found, penetrates—

	Feet.
1. Yellow till	15
2. Blue till, soft	140
3. Blue till, hard	39
Total	194

On the south slope of the moraine in the western part of the county, water-bearing sand or gravel is usually found at about 40 or 50 feet.

Following the moraine northeastward to Valparaiso, the till is found to give place in its lower portion to beds of sand and gravel. In the southern part of Valparaiso, and also for some distance south of the city, wells often obtain water at a depth of 25 feet. Occasional deeper wells in that district show a large amount of coarse sand or fine gravel below a few feet of surface till. On the elevated ground in the north-

ern part of Valparaiso wells usually penetrate about 30 or 40 feet of yellow and blue till, underlain by dry sand, which is often penetrated 50 or 60 feet before water-bearing sand or gravel is reached. The drift is of this character for several miles northeast from Valparaiso, and wells are often carried to a depth of 130 to 160 feet before obtaining water. For example, a boring at Jackson Center penetrates—

	Feet.
1. Yellow till	20
2. Dry sand	90
3. Blue-gray clay, tough and spongy	45 or 50
4. Water-bearing sand	10
Total	170

In some wells near Jackson Center a water-bearing sand is found at the top of the blue clay (No. 3) at about 120 feet. Where this is too fine to be easily screened the wells continue through the blue clay, obtaining water in coarse sand at 160 to 175 feet. Near Flint Lake the wells are 100 to 130 feet deep and obtain water in the sand above the blue clay.

In southern Porter County a boring for gas at Boone Grove penetrates—

	Feet.
1. Yellow loamy clay	8
2. Water-bearing sand	92
3. Hard blue till	40
4. Black shale (Devonian)	125
5. Limestone	15
Total	280

In the gravel plain south of the Valparaiso moraine wells usually obtain water at 10 to 20 feet, without penetrating any till. The gravel in places, however, does not coat the sheet of till that lies outside the moraine. Thus at Kouts Station there is a surface till 18 or 20 feet, beneath which water is obtained in a deposit of gravel at 25 to 35 feet. At Hebron, also, wells encounter till, and water is found at about 40 feet.

The Kankakee marsh extends several miles north of the river in the southern part of the county, and this area is so generally covered with water that it is unfit for settlement.

LAPORTE COUNTY.

General statement.—Laporte County is situated immediately east of Porter. It fronts for a few miles on Lake Michigan, on its northern boundary, but that boundary is formed mainly by the State line. The southern boundary is formed mainly by the Kankakee River, but in the southeastern part the county extends a few miles beyond the river. The width of the county is 21 to 23 miles and the length is 22 to 32 miles, being greatest at the western border. The area is 540 square miles.

The Valparaiso moraine leads northeastward across the northwestern portion of the county and has a width of about 6 miles. Its crest has an elevation of 225 to 300 feet or more above Lake Michigan. It incloses several lakes, from one of which the city water supply of Laporte is obtained. It rises very abruptly on its northwest border above the low plain that lies between it and Lake Michigan, but on its southeast border a gravel outwash from the moraine is built up nearly to the level of the crest, and the descent is gradual from the moraine to the Kankakee marsh. The marsh stands fully 100 feet above Lake Michigan in eastern Laporte County and about 75 feet at the western border of the county. It is, therefore, 150 to 200 feet or more below the crest of the moraine. The gravel plain makes a descent of 75 or 100 feet in the interval of 8 or 10 miles between the moraine and the marsh.

On the low plain bordering Lake Michigan, in the northwestern part of the county, there are a series of narrow till ridges or feeble moraines which govern the drainage of that region to a marked degree, though having a relief of but 30 to 50 feet. On the immediate border of the lake there are prominent dunes, rising in places to a height of 150 feet above lake level.

The glacial deposits are so heavy that ordinary wells are obtained without entering the underlying rock. A boring for gas at Lacrosse, in the southern part of the county, is reported to enter rock at 38 feet. The gas boring at Laporte, the county seat, penetrates 295 feet of drift. The gas boring at Michigan City penetrates 250 feet, while the artesian well at the penitentiary at Michigan City penetrates only 170 feet. These borings indicate that the thickness varies greatly, and are scarcely sufficient to justify an estimate of the average thickness for the county.

Individual wells.—The gas-well boring at Michigan City has the following section:

	Feet.
1. Dry surface sand	15
2. Quicksand	10
3. Gravel	5
4. Blue till, pebbly and rather hard	167
5. Gravel containing cobble and bowlders	15
6. Sand and gravel, with occasional large stones	40
7. Limestone, with thin beds of shale, extending to the bottom of the well	570
Total	819

At a depth of 210 feet a flow of fresh water was obtained from the drift, with a head 15 feet above the surface. The strength of the flow increased downward to the rock at 250 feet. A strong flow of sulphur water was obtained from the limestone at about 450 feet.

The artesian well at the penitentiary, 1 mile west of Michigan City, has the following section reported by Dr. Levette:[1]

	Feet.
1. Surface sand	48
2. Clay	4
3. Sand	24
4. Clay	66
5. Sand	80
6. Marcellus shale	76
7. Upper Silurian limestone, with fossils	293½
Total	541½

The boring is reported to terminate in a porous limestone rock which furnishes a flow of water strongly impregnated with sulphureted hydrogen. Its head is 22 feet above the surface of the ground; rate of discharge about 300 gallons per minute; temperature, 57° F. The well mouth being about 18 feet above the level of Lake Michigan, or 600 feet above tide, the head at this well is 622 feet above tide.

A remarkable instance of the rise of water in a sand dune above lake level, was found at the Yankee Slide, a dune on the shore of Lake Michigan, in the west part of Michigan City. Wells on its slope, at an altitude of 40 or 50 feet above the lake, obtain water at a depth of but 12 feet.

The wells on the low plain in northwestern Laporte County, and also on the till ridges which traverse that plain, show a preponderance of till. The water-bearing sand and gravel appears to be in local deposits or sheets of limited extent. Neighboring wells often have very dissimilar sections. In some a sand or gravel bed appears, which is absent in others; some show a solid bed of till to a depth of 75 or 100 feet, while others present alternations of till with sand or gravel. The deepest well record obtained on this plain is that at a farmhouse 4½ miles south of Michigan City, and is as follows:

	Feet.
1. Yellow till	20
2. Dry sand	8 to 10
3. Blue till	85 to 90
4. Sand	50
Total	165

There are beach lines traversing this plain immediately south and east from Michigan City, on which wells are sometimes obtained at depths of 12 to 16 feet without reaching the bottom of the beach deposits.

On the north slope of the Valparaiso moraine, near the west line of the county, and just south of the Lake Shore and Michigan Southern Railway, a well 148 feet in depth enters dry sand below till at about

[1] Fifth Ann. Rept. Indiana Geol. Survey, 1873, pp. 470-471.

20 feet, which continues to the water-bearing sand and gravel near the bottom. Occasional deep wells along this moraine show that sand and gravel, as in the above section, greatly preponderate over the till. As a rule, however, wells are obtained along the moraine without penetrating to greater depth than 50 feet.

Wells on the gravel plain, south of the moraine, are usually obtained at 10 to 20 feet. Several villages situated on this gravel plain depend upon these shallow wells for drinking water, though the water appears liable to contamination.

The gas-well boring near Lacrosse, in the southern part of the county, enters water in gravel 5 feet below the surface, and wells in that vicinity are only 10 to 17 feet in depth. The boring was carried to a depth of 838 feet, but water does not rise above the surface, which is 675 feet above tide. The well is used for watering stock.

ST. JOSEPH COUNTY.

General statement.—St. Joseph County is situated east of Laporte, about midway of the north boundary of the State. Its area is 470 square miles. About one-half the county is a gravel plain formed by the outwash from the ice sheet. In the northwestern portion of the county the outwash is from the Valparaiso moraine, and the plain descends from about 800 feet at the border of the moraine to 725 feet at the border of the Kankakee marsh. In the southwestern portion of the county the outwash is westward from the Maxinkuckee moraine of the Saginaw lobe, and there is a similar descent from the moraine to the Kankakee marsh. In the northeastern portion of the county there is an extensive gravel plain along the St. Joseph River, whose head is in southern Michigan in a later moraine of the Saginaw lobe. The southeastern part of the county is occupied by a till plain which borders the Maxinkuckee moraine on the east. The Maxinkuckee moraine passes diagonally across the county from the southwest to the north border and has a width of about 5 miles. It is interrupted by a gap at the St. Joseph River near South Bend 2 or 3 miles in width. The highest portions of this moraine stand fully 300 feet above Lake Michigan, or about 900 feet above tide.

Very little is known concerning the thickness of the glacial deposits, there being, so far as the writer is aware, but one point within the county where rock has been struck. A gas boring at South Bend, in the valley of St. Joseph River, has 137 feet of drift. Its altitude is but 725 feet above tide, or fully 150 feet lower than the uplands of the southeastern portion of the county. If, therefore, the rock surface has a general level as low as at South Bend, the drift of the county would be from 120 to 300 feet in thickness, with an average of perhaps 200 feet.

Individual wells.—The gas-well boring at South Bend is reported by Dr. Phinney[1] as follows:

	Feet.
1. Sand	25
2. Gravel	20
3. Clay	30
4. Sand	25
5. Gravel	37
6. Shales	238
7. Limestone	805
8. Limestones and shales	220
9. Utica shale	185
10. Trenton limestone	85
Total	1,670

Salt water was struck at 375 and 610 feet, and also in the Trenton at 1,670 feet. From the latter horizon it rose within 200 feet of the surface.

The city of South Bend obtains its water supply from about 30 flowing wells, situated along the valley of the St. Joseph River. The wells have a depth of 100 to 125 feet, with an average of about 110 feet. They are obtained in gravel beneath a bed of clay 20 to 40 feet in thickness, which acts as a cover and prevents contamination of the water. This clay is probably a water deposit rather than a glacial deposit, as it is described as entirely free from pebbles of any kind. The head is sufficient to carry the water above the surface only on the low ground along the river bottom, about 670 feet above tide. The gravel plain on which the city was built stands 20 to 30 feet or more above the height to which the water will rise.

The private wells in South Bend are often obtained without penetrating a bed of clay, and the ground water is usually at sufficient height to easily receive the leaching from cesspools. Such wells may become a source of danger to the health of the city.

Wells in the city of Mishawaka are also situated on a gravel plain, and are usually about 20 feet in depth, and the water stands within 12 feet of the surface. There appear in the majority of cases to be no beds of clay or other impervious material to prevent contamination of the water from cesspools. The St. Joseph River, drawn upon for fire protection and irrigation, might easily be made to furnish the supply for domestic use.

Wells on Portage Prairie, a gravel plain in the northwest part of the county, are usually 60 or 80 feet, and seldom less than 40 feet, in depth. A well on this prairie, at Mr. Womer's, near the State line, 174 feet in depth, has the following section:

	Feet.
1. Sand and gravel, with water near bottom	67
2. Blue clay and blue quicksand	99
3. Gravel and sand, with water	8
Total	174

[1] Eleventh Ann. Rept. U. S. Geol. Survey, 1889-90, Part I, 1891, p. 734.

Wells on the gravel plain west of the Maxinkuckee moraine, near North Liberty, usually enter clay below the gravel at about 20 feet. Two wells in the Potato Creek valley, east of North Liberty, obtain flows of water from depths of 45 and 70 feet.

Wells at Walkerton, also on the gravel plain, obtain water at 20 or 30 feet. The water surface is usually nearly 20 feet from the mouth of the well, but even this depth is not sufficient to insure freedom from contamination, there being no impervious stratum above the water vein.

A well on the gravel plain between Walkerton and North Liberty, in sec. 5, T. 35, R. 1 E., 160 feet in depth, is mainly through sand and gravel. The water rises nearly to the surface. Wells in that vicinity usually obtain water at 10 to 20 feet. One well near Walkerton, however, failing to obtain water in the surface gravel, passed through a pebbleless blue clay 50 feet in thickness, obtaining water at a depth of 70 or 80 feet.

Records of two deep wells were obtained on the Maxinkuckee moraine, about 8 miles south of South Bend, in sec. 17, T. 36, R. 2 E. One at Mr. Sweeney's, 131 feet in depth, after penetrating 22 feet of yellow till, passes through alternations of sand and blue till for about 100 feet before reaching the coarse gravel. The other well, at Mr. McClelland's, has a similar section and is 146 feet in depth.

On the plain east from the Maxinkuckee moraine many wells are but 15 to 20 feet in depth, and enter sand or gravel below till near the bottom. A few tubular wells are 80 or 100 feet in depth.

ELKHART COUNTY.

General statement.—Elkhart County is situated immediately east of St. Joseph County, on the north boundary of the State, and has an area of 470 square miles. Like St. Joseph County, a large portion of its surface is a gravel plain. The most extensive gravel plain is that along the St. Joseph River, in the northwest part of the county, which comprises an area of more than 100 square miles. There is also a gravel plain along the Elkhart River from the southeast corner of the county northwestward to the St. Joseph gravel plain. From the Elkhart gravel plain there are extensions southward into Kosciusko County, past New Paris and Milford, and southeastward into Noble County near Cromwell. This system of gravel plains comprises an area of fully 100 square miles. There is also a narrow gravel plain along Little Elkhart River, in the northeast part of the county. About half the county is, therefore, embraced in the gravel plains. The uplands consist of a till plain having an area of about 125 square miles, situated in the southwest part of the county, and of morainic belts, with small areas of nearly plain surface, occupying an area of about 150 square miles in the eastern and southern parts of the county. The altitude of the gravel plains is mainly below the 800-foot

contour. The uplands are mainly between 800 and 900 feet above tide, though small areas on the moraines in the eastern and northeastern parts of the county rise above 900 feet.

The thickness of the drift is known at three points—Elkhart and Goshen, and near New Paris, where it is 122, 162, and 90 feet, respectively. Should the rock surface of the entire county be as low as at these wells, the thickness of the drift would average fully 200 feet.

Individual wells.—At Elkhart the majority of wells are about 30 feet in depth. They penetrate sand and gravel for 20 feet or more, when a thin bed of clay is usually found as a cover for the water-bearing gravel. The mayor reports that he considers the clay a protection against contamination.

A few wells in Elkhart have been put down to a depth of 100 to 120 feet, which have sufficient head to overflow on the low ground near the streams. They penetrate usually a large amount of blue clay, and obtain water in a coarse gravel or cobble near the base of the drift. The water from these flowing wells is chalybeate.

At Goshen the city water supply is from a large well, 34 feet in depth and 30 feet in diameter. After penetrating a few feet of surface sand, it passes through 19 feet of blue clay, which is thought to insure its freedom from contamination. The water is obtained from a coarse sand beneath the blue clay. Its head is sufficient to bring it to the level of the well mouth.

One of the gas-well borings at Goshen was carried only to the Lockport limestone, where salt water was struck which rose to the surface. Another gas-well boring in that city was carried to a depth of 239 feet into the Trenton (Phinney). So far as known no use is made of the water from either of these wells.

In the vicinity of Middlebury, in the eastern part of the county, on the elevated portions of the moraine, tubular wells are usually 80 or 100 feet deep and penetrate a large amount of till.

A well on the border of the St. Joseph gravel plain in the northeast part of the county, in sec. 27, T. 38, R. 7 E., is mainly through gravel to a depth of 65 feet. Wells on this plain are usually but 15 or 20 feet.

Near New Paris, on the border of a morainic ridge, one well penetrates till to a depth of 110 feet, another, 1 mile north, 102 feet in depth, is mainly in sand and gravel. It is thought to have struck rock at about 90 feet. The morainic tracts in that vicinity usually contain more gravel and sand than till. Knolls are often composed largely of gravel. In the eastern and northeastern part of the county the morainic tracts contain a larger proportion of till.

The upland plain in the southwestern portion of the county is a continuation of the plain of southeastern St. Joseph County, and its wells have similar depth and structure, being through till for a distance of 20 or 25 feet, when a water-bearing sand or gravel is struck.

In some cases wells are obtained at about 10 feet in a bed of sand or gravel between the yellow and blue till. A few tubular wells have been sunk to a depth of 80 or 100 feet to a water-bearing sand or gravel below a sheet of blue till.

LAGRANGE COUNTY.

General statement.—Lagrange County is situated immediately east of Elkhart, on the north boundary of the State, and has an area of 384 square miles. It is one of the most elevated counties in the State, the greater part of its surface being above the 900-foot contour, while several tracts in the eastern part of the county, aggregating an area of perhaps 75 square miles, stand above the 1,000-foot contour. It has several small morainic belts, formed by the Saginaw lobe during its recession. It has also conspicuous morainic hills in its northwestern corner and on the eastern border of the county. There is one extensive gravel plain in the county, traversed by Pigeon River. It lies on the southwest border of a prominent Saginaw moraine, which occupies northeastern Lagrange County and passes northwestward into Michigan. This plain has a breadth of 2 to 6 miles and traverses nearly the entire width of the county, a distance of over 20 miles. Aside from this main gravel plain there are small areas underlain by gravel, one of which, known as the Haw patch, covers several square miles on the southern boundary of the county; another borders the Little Elkhart River in the western part of the county.

So far as known to the writer, the bottom of the drift has been reached by only one boring in this county, though it has been penetrated to a depth of 200 feet in several wells, and there are numerous wells 100 feet or more in depth. It is thought by Dr. C. R. Dryer[1] that a farm well in southwestern Lagrange County may enter black shale at 150 feet.

Individual wells.—On the strong morainic belt in the northwest part of the county the sharpest knolls are usually made up of gravel and sand, but those of gentler contour often contain till. The wells vary greatly in depth, some being but 15 or 20 feet, while others are 50 to 75 or more. On the overwash gravel plain south of this moraine wells are obtained in gravel at about 20 feet.

In a feeble moraine on the north side of Little Elkhart River, in the western part of the county, the wells are usually about 30 feet in depth; after penetrating 10 to 20 feet of till they enter sand. South of Little Elkhart River the wells are mainly through till. The average depth is 30 or 40 feet, but occasional wells reach 60 feet.

In the gravel plain along Little Elkhart River the wells are usually but 12 to 20 feet in depth, entirely through gravel and sand.

At Lagrange wells are obtained at about 100 feet at the city waterworks, but private wells seldom exceed 40 feet. The detailed record

[1] See Eighteenth Ann. Rept. Indiana Geol. Survey, p. 81.

of four of the waterworks wells, published by Dr. Dryer,[1] show alternations of sand and gravel with till, in which the thickest beds are but 20 to 25 feet. In well No. 1, 92 feet in depth, the gravel beds amount to 32 feet, the thickest bed being 12 feet in the upper part of the section. In well No. 2, 102 feet in depth, the gravel and sand amount to 47 feet, of which 17 feet occur at the bottom of the well. In well No. 3, 98 feet in depth, the sand and gravel amount to 34 feet. In well No. 4, 111 feet in depth, the sand and gravel amount to 33 feet. These wells are within the area of an ordinary town lot, and yet Dr. Dryer reports that the majority of strata can not be correlated in any two of them. In well No. 1 there are 6 beds of gravel; in wells Nos. 2–4, but 5 beds of sand and gravel.

A well near the jail at Lagrange penetrates—

	Feet.
1. Yellow till	8
2. Dry sand	30
3. Gravel with water	2
Total	40

A prospect boring for artesian water at the jail penetrated—

	Feet.
1. Yellow till	15
2. Blue till, with thin beds of sand	50
3. A brown mold or soil	4
4. Cemented gravel	5
5. Loose gravel with water	8
6. Blue till	45
7. Cemented gravel	8
8. Dry sand and gravel	70
Total	205

The boring was abandoned without obtaining a flow or reaching rock strata.

A well on a sharp morainic ridge about 4 miles east of Lagrange, 202 feet in depth, failed to find water. Another well on the same farm obtained water at 175 feet. Both wells were mainly through till. A neighboring well, only 62 feet in depth, obtained water in gravel below till at about 60 feet.

A well for Dr. Drake, one-half mile north of Valentine, has the following section:

	Feet.
1. Sandy yellow till	10
2. Blue till	41
3. Gravel with inflammable gas	3
4. Blue clay	46
5. Black muck with leaves and inflammable gas	6
6. Soft blue clay	24
7. Water-bearing sand, coarse at bottom	10
Total	140

[1] Eighteenth Ann. Rept. Indiana Geol. Survey, pp. 80-81.

A well in the southeast part of the county, one-half mile east of South Milford, penetrates—

	Feet.
1. Sandy yellow till	20
2. Blue till	49
3. Very fine sand	20
Total	89

A similar fine sand was found in the well at Joseph Ryer's, 4 miles north of Wolcottville, at 30 to 108 feet from the surface.

A well in the west part of Milford Township, 3 miles north of county line, 97 feet in depth, is largely through sand, gravel, and cobble.

In the vicinity of Pretty Lake and Long Lake, in Milford Township, in the southeast part of the county, there are gravel plains on which wells obtained water at 30 or 40 feet without reaching the bottom of the gravel. On bordering districts wells usually penetrate 25 to 40 feet of till before reaching a water-bearing gravel.

Dr. Dryer reports the occurrence of coal in the drift beds in the southwest part of the county at depths of 76 feet in two neighboring wells under which beds of water-bearing gravel occur. A boring on a neighboring farm is thought to strike shale at 150 feet.

STEUBEN COUNTY.

General statement.—Steuben County is situated in the extreme northeast corner of the State, having Michigan on its northern and Ohio on its eastern boundary. On its western border is Lagrange and on its southern border Dekalb County. Its area is about 330 square miles. The entire county, except a valley in its southeast corner, stands above the 900-foot contour, and a portion of it rises above 1,100 feet, with occasional points 1,150 feet or more. It is estimated that at least one-half of the county stands above the 1,000-foot contour. The great elevation of this county is not due to an elevated rock surface, but to the heavy accumulations of drift. Its western half is occupied by the great interlobate moraine formed between the Erie lobe and the Saginaw lobe.

The topography of the western half of the county is of the knob-and-basin type, and several lakes are inclosed among the morainic knolls and ridges. These lakes have the advantage of beautiful scenery, pure water, and an excellent stock of fish. They are justly the pride of the inhabitants of the county. The largest lake, James Lake, has a length of 5 miles and an average width of half a mile. It is situated near the north line of the county and surrounded by sharp morainic knolls, which rise in places to a height of more than 100 feet above its surface. About this lake is a group of smaller ones, among which Jimerson, Crooked, Loon, Center, and Gage lakes are worthy of mention. These lakes are all tributary to Fawn River and discharge northwestward. South of them is a chain of lakes,

which are traversed by Pigeon River. Pleasant Lake, the most conspicuous of these lakes, is about 1 mile in length and one-fourth mile in average width. Below this lake the stream passes through Golden Lake and Hogback Lake, the latter receiving its name from a precipitous ridge of bowlders and gravel which stands on its shore. In the extreme southwestern part of the county is another chain of lakes drained by Turkey Creek, a south tributary of Pigeon River. The largest of these, Big Turkey, has a length of about 2½ miles and a maximum width of one-half mile.

A moraine of the Lake Erie lobe traverses the eastern part of the county in a north to south direction. This has gentler contours than the interlobate moraine, but incloses several lakelets among its knolls and ridges. The most conspicuous are Clear Lake, in the northeast corner of the county, having an area of about 2 square miles, and Fish Lake, in the southeast corner, having an area of a little more than 1 square mile. These lakes are tributary to the St. Joseph-of-the-Maumee River. A detailed discussion of the several lakes just mentioned, with observations on the size, depth, and character of their bottoms, is presented by Dr. Dryer in his report on Steuben County.[1] To this report the writer is indebted for the data concerning the dimensions of the lakes. It is suggested by Dr. Dryer that the city of Fort Wayne could find no better source of water supply than these lakes in the southern part of Steuben County.

The only level land in the county of notable extent is found in a narrow plain lying between the interlobate moraine and the Erie moraine just mentioned. It has a breadth of 2 to 5 miles and extends the entire length of the county.

The valleys of Fawn River, Pigeon River, Turkey Creek, and Fish Creek traverse gravelly districts, in which wells may be obtained at comparatively slight depth. The interlobate moraine varies greatly in the constitution of its drift and in the depth at which water may be obtained. Wells are not, however, as a rule, difficult to obtain, their average depth being not more than 30 or 40 feet. On the Erie moraine, in the eastern part of the county, and also on the plain west of it, the drift is largely a compact till, and the wells are not infrequently put down to a depth of 100 feet or more.

So far as known no wells in the county have reached rock, but the greatest ascertained depths are not more than 160 to 175 feet.

Individual wells.—Wells in the vicinity of Angola present much variety in material penetrated. Immediately north of the city is a small district where they obtain water at depths of 20 or 30 feet. Some wells in the city also obtain water at slight depth after penetrating a few feet of till. Several wells are put down to depths of 80 to 100 feet

[1] Seventeenth Ann. Rept. Indiana Geol. Survey, 1891, pp. 120-134.

or more. A well at the Tri-State Normal College has the following section:

	Feet.
1. Yellow till	20
2. Blue till	3
3. Reddish gravelly clay, with thin beds of sand	75
4. Gravel with water	6
Total	104

A well on the moraine west of Angola, near Fox Lake, 130 feet deep, was mainly in till. A well 3 miles north of Angola, of the same depth, was mainly in sand and gravel. On a gravel plain on south side of Turkey Lake two wells have a depth of 114 feet, largely through till after penetrating a few feet of surface gravel. A well on an elevated part of the moraine west of Turkey Lake in section 33, Salem Township, 90 feet in depth, was mainly in till. A well 2 miles southeast of Salem Center, 160 feet in depth, penetrates yellow or gray till 40 feet, below which it was mainly in blue till.

Near Hudson wells 80 feet in depth penetrate about 30 feet of sand and gravel and then enter blue till. A well 3 miles west of Hudson, 100 feet in depth, was mainly till.

Wells near Metz, in the eastern part of the county, are frequently 100 feet in depth, mainly till. One well 2 miles southwest of Metz, 103 feet in depth, is in till to within 2 to 3 feet of bottom.

Wells in the vicinity of Fish Lake, in the southeastern part of the county, obtain water in gravel at 15 to 25 feet. But within 2 miles back from the lake are frequently through till to a depth of 100 feet and occasionally 150 feet.

DEKALB COUNTY.

General statement.—Dekalb County is situated on the eastern boundary of the State, immediately south of Steuben. It has an area of 370 square miles. Its northwestern corner is occupied by the interlobate moraine of the Erie and Saginaw lobes. The higher part of the moraine rises above the 1,000-foot contour, but its eastern border stands only about 900 feet. The greater part of the county is occupied by a till plain, standing about 850 to 900 feet above tide. In the southeastern part, on the borders of the St. Joseph-of-the-Maumee, are two moraines of the Erie lobe, but they rise scarcely 25 feet above the border plains.

Over the greater part of the county there is a sheet of till extending to an average depth of about 50 feet from the surface, in which water is seldom obtained in large amount. Below this sheet of till the drift appears to be very largely sand and gravel and yields an unlimited amount of water. There are narrow belts or small areas, usually bordering the valleys, in which water may be obtained in gravel or sand at comparatively slight depth.

The thickness of the drift in this county has been determined at four villages, as follows: Butler, 378 feet; Waterloo, 365 feet; Auburn, 280 feet; Garrett, 318 feet. A boring in the extreme southeastern part of the county, near Spencerville, was carried to a depth of 198 feet without reaching rock. A boring at Kendallville, just west of this county, penetrated 485 feet of drift. These borings, together with the four which strike rock within the county, have sufficiently wide distribution to justify the interpretation that the drift of the county probably averages over 300 feet in thickness, and may possibly average 400 feet. The four borings which enter the rock are on a till plain which stands more than 100 feet below the elevated northwestern portion of the county. The rock floor in but one instance (at Auburn) stands above the level of Lake Erie.

Individual wells.—The gas boring at Butler is reported by Dr. Dryer to have the following section:

	Feet.
1. Hardpan (till)	15
2. Gravel and coarse sand	275
3. Red quicksand	40
4. Compact clay	45
5. Cobblestones and bowlders	8
6. Black shale	108
7. Limestone	1,064
8. Shale	500
9. Trenton limestone penetrated	89
Total	2,139

Water in large amount is found in the glacial drift. Salt water was struck in the Trenton.

The water wells in the vicinity of Butler usually obtain their supply from depths of 20 to 35 feet, though they are occasionally put down to a depth of 150 feet. In the northern part of the county, 6 or 8 miles northwest from Butler, wells are through till to a depth of 60 or 80 feet before striking water-bearing gravel or sand. The record of a well 3 miles south of Hudson was also obtained, which penetrated 75 to 80 feet of till.

At Waterloo the drift at the gas well is as follows:

	Feet.
1. Till	40
2. Sand and gravel with water	270
3. Blue clay without pebbles	45
4. Gravel and cobble	10
Total	365

At Auburn two gas wells each penetrate about 280 feet of drift, which is largely till in its upper half and largely sand and gravel in lower half.

There are occasional shallow flowing wells in the vicinity of Auburn on low ground on the border of Cedar Creek, water being obtained from the gravel below the till. The head is seldom more than 2 to 5 feet below the surface in that locality.

The gas boring at Garrett penetrates about 50 feet of till, beneath which is 200 feet or more of sand, with a thin bed of gravel at the bottom of the drift. This sand and gravel afford a large amount of water. In Garrett water is often obtained at 40 feet, but the wells are in some cases 75 to 100 feet. North and west from Garrett there are extensive marshes with sandy borders, where wells are obtained at slight depth without entering the till.

Along Cedar Creek Valley, in the southern part of Dekalb County, water is usually obtained at 30 or 40 feet. The wells penetrate more gravel than till, though both are present.

A well in the southeastern part of the county, near the village of St. Joseph, and but a few rods from the bank of the river, 110 feet in depth, is mainly through sand and gravel.

A well on the farm of Christian Hirsh, east of St. Joseph River, near Spencerville, has the following section:

	Feet.
1. Yellow till	10
2. Blue till	59
3. Fine sand	120
4. Gravel	9
Total	198

In that neighborhood there are perhaps a dozen other wells 60 to 100 feet in depth, mainly through till.

NOBLE COUNTY.

General statement.—Noble County is situated immediately east of Dekalb and has an area of 420 square miles. The entire county has a morainic topography, the greater part of it being the interlobate moraine of the Erie and Saginaw lobes. In the northwestern part of the county the Saginaw moraines branch off from the interlobate belt, while in the southeastern part an Erie moraine is parallel to and closely associated with the interlobate belt.

The portion of the county occupied by the interlobate moraine includes many lakes, some of which have an area of 1 to 2 miles or more each. The most important ones are Crooked, Tippecanoe, and Loon lakes, in the southern part of the country, which constitute the head waters of Tippecanoe River. There are several in the northern part of the county and in the adjacent portion of Lagrange County, constituting the head waters of Elkhart River. A few in the western part of the county are also tributary to Elkhart River. These lakes are usually bordered by extensive marshes, though in a few cases morainic knolls and ridges rise from their immediate borders. Those in the southern part of the county tributary to Tippecanoe River have less marshy borders than the lakes tributary to the Elkhart, and the morainic hills in that portion of the county also rise more prominently above the lake basins than in the northern or western portion of the county. While the beauty of scenery does not equal

that around the lakes of Steuben County, the quality of the water is excellent and the lakes are well stocked with fish.

Except in the southeastern portion of the county wells are usually obtained at moderate depths, seldom exceeding 50 feet. The interlobate moraine and the Saginaw moraines connected with it contain usually a large amount of sand and gravel with the till. The Erie moraine, on the southeast border of the county, has much less sand and gravel associated with it, and in consequence many wells need to be sunk to a depth of 100 feet or more.

The thickness of the drift is known at three points, Ligonier, Kendallville, and Albion. At Kendallville it is 485 feet and at Albion 375 feet, but at Ligonier it is only 169 feet. It seems probable that the average thickness of the drift for the county may equal that at Albion.

Individual wells.—The following detailed record of the drift penetrated at Albion was kept by Prof. W. B. Van Gorder, of that city:

	Feet.
1. Yellow clay	10
2. Blue clay	10
3. Sand and gravel	115
4. Blue clay	20
5. Sand and gravel, with streaks of blue clay	52
6. Sand and gravel	81
7. Blue clay, with thin beds of sand	52
8. Gravel	5
9. Red bowlder clay	15
10. Sand	5
11. Slate (?)	1
12. Sand	9
Total	375

The water wells at Albion are usually obtained at 60 to 100 feet in the sand and gravel below the upper sheet of till. They penetrate from 15 to 30 feet of till at the surface. The underlying sand is either too fine or contains too little water in its upper portion to supply the wells.

The drift at the Kendallville gas-well boring (485 feet), specimens of which were preserved in a glass tube, appears to be mainly sand and gravel below a depth of 20 feet. A record of a water well in this village near the gas well was furnished by the driller, J. Hart, and is as follows:

	Feet.
1. Yellow till	10
2. Dry sand	15
3. Sand, with some gravel, but little water	50
4. Soft blue till	29
5. Gravel, with large amount of water	4
Total	108

A still deeper well at Dr. Mayer's residence in Kendallville is reported by the driller, Mr. Diebolt, to have the following section:

	Feet.
1. Surface clay	5
2. Dry gravel	20
3. Water gravel	10
4. Soft blue clay	25
5. Water gravel	20
6. Hard blue till	70
7. Soft blue till	25
8. Water gravel	10
Total	185

A well at Mr. Henry Mayer's in the east part of Kendallville, 60 feet in depth, penetrates—

	Feet.
1. Yellow till	28
2. Blue quicksand	26
3. Ferruginous crust	1
4. Water gravel	5
Total	60

From these sections it appears that the drift may have considerable variability within the limits of the village.

A well about 3 miles east of Kendallville, in section 1, Allen Township, penetrates—

	Feet.
1. Yellow till	14
2. Blue-gray till, with thin beds of sand or gravel	192
Total	206

This well is in the Erie drift above referred to.

A well 4 miles northeast of Kendallville is reported to penetrate 120 feet of till, and one in the extreme northeast corner of the county 75 feet, before obtaining water.

It is reported by Mr. Diebolt that the blue till of the Erie drift found south from Kendallville is much harder to penetrate than the blue till of the Saginaw drift found north and west of that village. A well 1 mile south from Kendallville penetrates—

	Feet.
1. Yellow till	20
2. Hard blue till	40
3. Cemented gravel	15
4. Water gravel	10
Total	85

A well in section 17, Allen Township, on a prominent drift knoll, is 177 feet deep, mainly in till.

Wells in the vicinity of Avilla, and for 5 or 6 miles west from that village, are frequently put down to a depth of 90 or 100 feet, mainly through till. Several wells in the southeastern part of the county,

in Swan and Greene townships, are reported to be mainly through till to a depth of 75 to 160 feet. Dug wells, however, are often obtained in that region at a depth of 20 to 40 feet from thin beds of sand or gravel included in the till.

In the district southeast and south from Albion records of several deep wells were obtained. One near Noblesville, 161 feet in depth, was entirely in till. Another in section 11, Greene Township, was in till to a depth of 100 feet before striking water-bearing gravel. A well in section 35, Jefferson Township, enters gravel below till at 63 feet. One in section 26, Jefferson Township, penetrates till, with thin beds of sand or gravel, to a depth of 102 feet. One in section 16, Jefferson Township, enters water-bearing gravel at 70 feet.

Northeast from Albion, in the vicinity of Rome City, one well, 117 feet in depth, penetrates—

	Feet.
1. Sand	53
2. Soft, adhesive blue clay	40
3. Sand and gravel	24
Total	117

Another, 122 feet in depth, penetrates—

	Feet.
1. Yellow till	20
2. Soft blue till	45
3. Quicksand	8
4. Soft blue till	44
5. Gravel with water	5
Total	122

A well in section 23, Wayne Township, 147 feet in depth, penetrates till, with thin beds of sand and gravel, its entire depth. Another well in the northern part of the same section has a depth of 164 feet in similar material. A well in section 27, 117 feet in depth, also has a similar section.

In the vicinity of Brimfield the surface is sandy to a depth of a few feet, but wells penetrate a large amount of till. One well, a mile east of Brimfield, 60 feet in depth, is mainly in blue till.

A well near Skinner Lake, 3 miles east of Albion, penetrates—

	Feet.
1. Yellow till	12
2. Soft blue till	52
3. Sand, with water	4
Total	68

In the northwest part of Noble County, near Hawville, wells show a variable structure, some being entirely in sand and gravel to a depth of 30 or 40 feet, while others are in till to even greater depths before striking a water-bearing gravel.

Wells in the southwestern part of the county usually have 40 to 75 feet, more generally 75 feet, of till at surface before entering beds affording a strong supply of water.

From Albion west and northwest the drift appears to be largely of a gravelly constitution and wells are obtained without penetrating to great depth. At Ligonier the depth is about 35 feet. The wells at that village usually penetrate 10 to 20 feet of till before entering the water-bearing gravel. This gravel is shown by the gas-well boring to be 125 feet in depth. There was a large supply of fresh water at about 200 feet in the gas boring, 30 feet below the rock surface.

KOSCIUSKO COUNTY.

General statement.—Kosciusko County is situated in the middle portion of the second tier of counties from the north boundary of the State, being immediately south of Elkhart County and west of Noble County. It has an area of 556 square miles, being exceeded in area by only two other counties in the State.

The eastern and southern portions of the county are situated on the interlobate moraine of the Saginaw and Erie lobe, except the extreme southeastern portion, which is occupied by a moraine of the Erie lobe (the Mississinewa). The northwestern portion of the county, comprising about one-fourth its area, is occupied largely by gravel plains and by marshes. It is much lower than the moraine, and yet the divide between the Wabash and the Lake Michigan drainage systems passes through it. The general elevation of the plain is about 800 feet above tide. The moraine stands 900 feet or more in its higher portion.

Along the interlobate moraine in the eastern portion of the county there are numerous lakes, one of which, Turkey Lake, has the distinction of being the largest lake in Indiana. The area is probably about 8 square miles, its length being fully 6 miles and its width a mile or more. There are probably a half dozen other lakes having areas of 1 to 2 square miles each, among which may be mentioned Wawasee, Tippecanoe, Boydstown, Barbers, Big Eagle, Little Eagle, and Pike lakes. These lakes are bordered on one or more sides by morainic knolls and ridges, but have usually extensive marshes on other sides. Turkey Lake lies on the inner border of a Saginaw moraine that leaves the interlobate moraine near the border of Noble and Kosciusko counties and passes northwestward into Elkhart County. Wawasee, Tippecanoe, and Boydstown lakes are situated on the outer border of the same moraine. These lakes have a pure supply of water and are said to be well stocked with fish. A biological survey of Turkey Lake is in progress under the auspices of the State University. A few small lakes occur along the interlobate moraine in the southern part of the county, among which may be mentioned Yellow Creek, Beaver Dam, Silver, and Rock lakes. None of these have an area of 1 square mile. They lie in the midst of morainic knolls and ridges, with but little marshy land on their borders.

This county is as well favored, perhaps, as any in the State in abundant supplies of water for wells at shallow depth. On the plain in the northwestern portion the wells rarely exceed 40 feet and are

usually but 10 to 20 feet in depth. Along the moraine, even in its most elevated portion, it is rare to find wells that exceed 40 feet in depth. The drift appears to consist more largely of sand and gravel than of till, unless it be in the extreme southeastern portion of the county occupied by the Erie moraine.

The thickness of the drift is known only in the vicinity of Warsaw, the county seat, where gas-well borings show it to be in one case 247 and in another 255 feet. A well 3 miles west of Warsaw penetrates 243 feet of drift.

Individual wells.—At Milford, on a gravel plain in the northern part of the county, the wells have a depth of about 20 feet, entirely through gravel and sand. In the vicinity of North Galveston, also on the gravel plain, wells enter till below the gravel at about 25 feet. In the vicinity of Oswego, also, the bottom of the sand and gravel is reached at 25 feet or less. Water is usually obtained at both these villages and in the intervening country near the base of the gravel. West from North Galveston the plain has a till deposit at the surface, being outside the limits of the gravel overwash. But wells usually find the water-bearing sand and gravel at 15 or 20 feet.

On Bone Prairie the wells are in some cases put down to a depth of 60 feet, largely through till, there being only a slight coating of surface gravel.

At Atwood wells range in depth from 8 feet to 40 feet, but usually obtain water below yellow till at about 20 feet.

At Etna Green wells penetrate 20 or 30 feet of till before entering water-bearing gravel.

In the eastern part of the county the wells along the Tippecanoe River and southward for a mile or two are only 10 or 12 feet in depth, largely in sand. North from the river they penetrate till to a depth of 30 to 50 feet.

On the border of Turkey Lake a well 40 feet deep is reported to have penetrated:

	Feet.
1. Gravel	12
2. Till	28
3. Water-bearing gravel at bottom.	

In the vicinity of Pierceton wells occasionally penetrate 60 feet or more of till. A tubular well 1 mile northeast of Pierceton penetrates till about 100 feet.

At Kosciusko there is a surface gravel several feet in depth, but wells usually pass through it and an underlying till into a deeper gravel at about 25 feet.

For 2 to 4 miles east from Warsaw the wells are largely through till and have a depth of 18 to 40 feet.

In the east part of Warsaw a flowing well has been obtained on low ground between Pike and Center lakes at a depth of 102 feet. Its head is about 4 feet above the surface. At one of the gas-well borings

in Warsaw there is also a flow of water discharging rapidly from a 7-inch pipe at a height of 2 feet above the surface. As it contains much sulphureted hydrogen, it is probable that a portion of the water is from the rock strata. The overflow is probably caused from accession of water from the drift. In both the gas-well borings at Warsaw the drift is largely sand, filled with water.

In the western portion of the county, south from the Tippecanoe River, in the vicinity of Claypool, Burkett, and Mentone, wells usually penetrate 25 to 40 feet or more of till and occasionally 60 feet.

MARSHALL COUNTY.

General statement.—Marshall County is situated west of Kosciusko County, in the middle portion of the second tier of counties from the north boundary of the State. It has an area of 440 square miles.

The prominent Maxinkuckee moraine leads through the western range of townships from south to north. It also swings southeastward near the southern boundary of the county and has its inner border within the limits of Marshall County as far east as the Tippecanoe River. This moraine constitutes the principal topographic feature of the county, the remainder of the county being a gently undulating plain, with occasional slight ridging of the drift.

Lake Maxinkuckee, from which the moraine takes its name, is situated in the southwestern township of the county and is surrounded by a series of morainic knolls and ridges, which add to the attractiveness of its scenery. The lake occupies perhaps 2 square miles, and its maximum depth is 76 feet. A large number of springs occur on its borders, and its water is remarkably clear and pure. The lake is said to abound in fish. On the borders of the lake several clubhouses have been built by Indianapolis, Peru, Plymouth, and other clubs, and summer cottages are numerous along its shore.

Along the border of the lake several flowing wells have been obtained, which rise to a height of 12 to 30 feet above the lake surface. The first well driven was only 13 feet in depth. Several have a depth of but 20 or 25 feet. Others are put down to a depth of 50 to 75 feet. One well has a depth of 160 feet, and one reached a depth of 203 feet. There appear to be several water horizons, but the head is no greater from the deep wells than from the shallow ones, and the upper horizon is as strong as any.

Two other prominent localities for obtaining flowing wells are found in this county, one being along Yellow River, in the vicinity of Plymouth, the other along Yellowbank Creek, in the vicinity of Teegarden. Those in the vicinity of Plymouth are usually but 40 or 50 feet. Those in the vicinity of Teegarden are 40 to 100 feet. In all cases the flowing wells are from beds of sand or gravel beneath a sheet of till.

The bottom of the drift has, so far as known to the writer, been

reached in but one locality, Plymouth, the county seat, where a gas boring entered rock at 242 feet.

Individual wells.—On the head waters of Yellow River, near Bremen, in the northeastern part of the county, wells are usually but 12 to 20 feet in depth and penetrate mainly sand and gravel.

At Bremen, however, there is a small ridge of till on which the average depth of wells is about 40 feet. One well in the west part of the village is 100 feet in depth, mainly blue till.

Wells at Inwood are mainly through sand and gravel, though penetrating thin beds of clay; the depth ranges from 20 to 50 feet. Between Inwood and Plymouth the usual depth is about 35 feet, water being obtained in sand or gravel below till.

The gas well at Plymouth has the following section of drift:

	Feet.
1. Sand and gravel	40
2. Till	50
3. Mainly sand and gravel	150
Total	240

Flowing wells in the vicinity of Plymouth are obtained in a narrow belt, scarcely 40 rods in width, along the Yellow River bottoms. They usually penetrate several feet of sand at the surface, below which are alternations of till with sand beds. The best flow is obtained at a depth of 42 to 45 feet.

The flowing wells along Yellowbank Creek are found for 2 or 3 miles west from Teegarden. They penetrate much blue till before reaching a water vein. The water horizon appears to vary greatly in depth in the several wells, there being a range from 40 feet to about 100 feet.

In the southern part of the county, on the plain east and north from the Maxinkuckee moraine, water is usually obtained at 10 to 20 feet. At Tippecanoe Station, on the borders of Tippecanoe River, the depth is but 10 or 15 feet. In the north part of Walnut Township, where the surface is sandy and poorly drained, wells seldom exceed 10 feet in depth. In portions of Walnut Township, although surface bowlders abound as in till tracts, yet the underlying deposits are mainly sand, and wells are found at depths of 10 to 20 feet.

The deepest of the flowing wells at Lake Maxinkuckee is at the residence of D. W. Morman. At the time of the writer's visit the water scarcely reached the surface, 20 feet above the level of the lake. Of the 203 feet penetrated, fully 90 per cent is thought to have been till, the sand beds being but a few feet in thickness.

Messrs. Thompson and Lee, in their report on Marshall County,[1] note two wells on the northeast shore which have a head 31 feet above

[1] Fifteenth Ann. Rept. Indiana Geol. Survey, pp. 182-186.

the surface of the lake. The wells are each 72 feet in depth and have the following section:

	Feet.
1. Soil and yellow clay	8
2. Sand	14
3. Blue clay	38
4. Sand and gravel	12
Total	72

A short distance east from these wells the head in a well 50 feet in depth is but 19 feet above the lake. The well at the Peru Clubhouse, on the east side of the lake, was bored to a depth of 160 feet and obtained only a weak flow. At the Indianapolis Clubhouse a good flow was obtained at only 27 feet. At the Highland House a well 33 feet in depth entered water-bearing sand at a depth of 13 feet. Near the Highland House D. W. Morman, of Indianapolis, has several wells. Four of them, averaging about 22 feet in depth, are estimated to have a combined discharge of 15 barrels per minute. These wells feed a ram which supply the grounds with water. Mr. Morman also has a deeper well, with the following section, in which the flow is obtained from the sand above the blue clay:

	Feet.
1. Yellow clay	11
2. Sand	25
3. Blue clay	62
Total	98

STARKE COUNTY.

General statement.—Starke County is situated on the eastern border of the head of the Kankakee marsh, in the northwestern part of the State. Its area is about 300 square miles. It is a much lower district than Marshall County on the east, and the surface is covered by sand dunes or marshes, except in the southeast portion, where a small till plain occurs which is nearly free from sand. Underneath the sand, throughout the inhabited portion of the county, a blue till is often found at depths of 10 to 40 feet, but wells are usually obtained in the sand above the till.

A boring at North Judson, for the purpose of obtaining natural gas, shows the drift to have a thickness of 198 feet. A gas boring at Knox also penetrated a large amount of drift, but the precise depth at which rock is struck has not been ascertained. In both borings till is entered below the sand at a slight depth and constitutes the main part of the drift.

Individual wells.—At Knox, the county seat, wells are obtained at various depths, ranging from 14 up to 40 feet, the deeper ones being on sand ridges and the shallow ones on low ground among the ridges. At the gas-well boring at Knox the water rose nearly to the level of

the surface, but the pipes have been withdrawn and the well abandoned. Some of the shallower wells are very liable to contamination.

At North Judson the water is obtained near the base of the sand at depths of 16 to 30 feet, the deeper wells being on sand ridges. There appears to be a liability to contamination of water in this village.

A boring at the north end of Cedar Lake, in the southeastern part of the county, is reported to have the following section:

	Feet.
1. Sand	5
2. Blue clay	9½
3. Sand and gravel	3
4. Blue clay	18
Total	35½

Cedar Lake is said to have a depth of 34 feet, with bowlder clay at bottom.[1]

Near the east border of the county several wells have been put down to depths of 30 to 100 feet, mainly through till. The deepest one (at Mr. Pette's, in sec. 24, T. 32, R. 1 W.), about 100 feet in depth, has the following section:

	Feet.
1. Yellow till	10 to 12
2. Blue till	16
3. Gray sand	52
4. Blue clay	4
5. Cemented sand and gravel	15
Total	97 to 99

A mile north from Mr. Pette's, at David Fetter's, a well penetrates—

	Feet.
1. Sandy till	5
2. Blue till	12
3. Quicksand	5
4. Blue till	30
Total	52

NEWTON COUNTY.

General statement.—Newton County is situated on the west border of the State, immediately south of Kankakee River. It has an area of about 400 square miles. The northern third of the county falls within the limits of the Kankakee marsh and the sandy ridges which form the southern border. The central portion of the county is occupied by a moraine 3 to 5 miles in width, which leads across it from west to east. This moraine rises from 50 to 75 feet above the bordering plains on either side and has a gently undulating surface. South from the moraine is a plain traversed by the Iroquois River, which extends southward beyond the limits of the county.

In the sandy northern portion of the county wells were, in the early days of settlement, put down to a slight depth and obtained their water in the sand; but within the past few years they have been

[1] Fifteenth Ann. Rept. Indiana Geol. Survey, p. 224.

sunk to depths of 50 to 100 feet or more, through a sheet of blue till which underlies the sand, to beds of sand and gravel which furnish a better quality of water than that in the surface sand. Along the morainic ridge wells are usually obtained in the glacial drift, but have occasionally been put down in the underlying rock. The distance to rock is 100 to 150 feet or more. The best wells on the moraine are deep ones, extending nearly to the base of the drift. The moraine appears to be composed of a nearly solid bed of till. In the plain south of the moraine many wells are sunk 75 to 100 feet or more to obtain a better supply of water than is afforded at shallower depths. On the immediate borders of the Iroquois River wells reach a depth of 100 feet without entering rock, but in the southern portion of the county rock is often entered at 25 feet or less. The rock surface appears to be generally much higher on the southern borders of the county than in the district north from the Iroquois River.

Individual wells.—Records of several deep wells in this county are presented in the Twelfth Annual Report of the State Geologist, and are also given below:

Twelve wells, bored by Hyer Brothers, in and near Kentland, penetrated, on an average, the beds named below:

	Feet.
1. Soil	2
3. Yellow clay	10
3. Blue glacial clay	45
4. Sharp sand	2
Total	59

Water rises to within 18 or 20 feet of the surface.

The well at the public square in Kentland obtained a flow of water at 300 feet and penetrated the following strata:

	Feet.
1. Glacial deposits	150
2. Black slate	73
3. Devonian limestone	25
4. Upper Silurian limestone	120
Total	368

At Kent's warehouse, in Kentland, an unsuccessful boring for water penetrated:

	Feet.
1. Glacial deposits	82
2. Black slate	80
Total	162

A well at Alexander Kent's, 1 mile northeast of Kentland, 320 feet in depth, penetrated 182 feet of drift. A well on his farm, 4 miles northeast of Kentland, found only 50 feet of glacial drift and obtained water in limestone at 53 feet. A well on another farm, 2 miles southwest of Kentland, struck limestone at 50 feet and there obtained water.

At Mr. Brush's, 3 miles southwest of Kentland, a flowing well has the following section:

	Feet.
1. Soil and yellow clay	9
2. Sand and gravel	4
3. Blue clay	68
4. Hardpan gravel	4
5. Limestone	1
Total	86

Another flowing well was obtained at Mr. Drake's, sec. 25, T. 27, R. 9 W., 3 miles east of Kentland. After penetrating 33 feet of till it enters a bed of sand and gravel, from which the flow is obtained.

Several flowing wells have been obtained in the Iroquois Valley on the overflow plain of the river. An average section of several of these wells, furnished by David McKenzie, their driller, is as follows:

	Feet.
1. Soil and sand	14 to 17
2. Blue clay	30
3. Hardpan gravel	5
4. Blue sand with flow of water	4
Total	53 to 56

A well near the State line west of Kentland, reported by Mr. McKenzie, penetrates—

	Feet.
1. Soil	3
2. Yellow clay	6
3. Blue glacial clay	25
4. Blue glacial clay with partings of sand	46
5. Gravel and fine sand	3
Total	83

A well on Mr. Peterson's farm, near the State line, in sec. 11, T. 28, R. 10 W., on a high part of the moraine, referred to above, penetrates 168 feet of drift without reaching the rock. Mr. McKenzie reports the following section:

	Feet.
1. Soil and yellow clay	6
2. Blue bowlder clay	154
3. Fine gravel and sand with water	8
Total	168

An almost identical series was found at Mr. Besicker's, in the adjoining section on the south, where a well 171 feet in depth was in till to a depth of 165 feet before striking water-bearing strata.

About 5 miles northwest from Kentland, in sec. 13, T. 27, R. 10 W., four wells on the farm of Mr. J. V. Speck are reported to have passed through a brown swamp muck at the bottom of the till, about 80 feet below the surface, beneath which there was water-bearing sand and gravel.

At Morocco a boring at the Creamery penetrated 127 feet of till, at which depth limestone was entered.

Several wells near the range line east of Morocco, on the north slope of the moraine, enter rock at 110 to 120 feet, after penetrating a solid bed of till.

At Mount Ayer, also on the moraine, near the eastern border of the county, many wells get a good supply of water in gravel at 30 or 35 feet, but a few have been put down to depths of 140 to 160 feet. Mr. Ashby's well penetrated 120 feet of drift and 20 feet of rock, as follows:

	Feet.
1. Yellow till	10
2. Blue sand	20
3. Blue till	90
4. Blue shale	20
5. Hard flint rock at bottom.	
Total	140

Mr. Lewis Marion's well in the southwest part of the village strikes shale at 139 feet. W. J. Young's well strikes shale at about 150 feet, and a hard rock at 162 feet. The drift is mainly till.

In the vicinity of Brooke a soft till is penetrated to a depth of 50 or 60 feet, below which there is a harder till, extending either to the rock or to water-bearing beds. Several wells between Brooke and the east line of the county overflow when on the low bottoms of the Iroquois River, and rise nearly to the surface on the plain that borders the river. Their depth ranges from 80 feet up to 120 feet or more. Rock is usually struck at 100 to 120 feet. The following section at J. B. Lyon's, 1 mile north of Brooke, will illustrate the structure:

	Feet.
1. Yellow till	10
2. Blue sand, very fine	5
3. Soft blue till	55
4. Blue-brown till	36
Total	106

Rock was struck at 106 feet. Water stands 12 feet below the surface.

In the southwest part of T. 27, R. 8 W., and southeast part of T. 27, R. 9 W., near the south line of the county, several wells strike rock at 40 or 50 feet or less, and there are occasional outcrops of the Lockport (often called Niagara) limestone in low knolls rising a few feet above the level of the bordering plain. Eastward from there to Goodland the drift appears to be generally thin. Rock is struck at about 20 feet. The wells which obtain their water from the Lockport limestone, in the southern part of the county, often reach a depth of 250 to 300 feet, and obtain a water charged with sulphureted hydrogen.

A natural gas boring at Kentland, 1,325 feet in depth, obtained a sulphurous water with head 45 feet below the surface. It supplies the waterworks.

JASPER COUNTY.

General statement.—Jasper County is situated in the northwestern part of the State, immediately east of Newton County and south of the Kankakee marsh. Its area is 570 square miles, the second county in area in the State. Like Newton County, its northern third is covered by the Kankakee marsh and by sand ridges that form the south border of the marsh. Its central portion is traversed by a continuation of the moraine that passes eastward across Newton County. Its southern portion is a plain covered quite extensively with sand, which in places is drifted into dunes.

In the northern part of the county the drift deposits are 75 to 200 feet in depth, but in the central and southern portions, although the altitude is as great as in the northern portion, the drift deposits are generally quite thin, there being often only a coating of sand 10 to 20 feet in depth. In some wells in the northern part of the county (cited below) a hard till is found below the soft Wisconsin till which is probably Illinoian drift.

Individual wells.—On the borders of the Kankakee marsh, in the northern part of the county, wells are usually obtained at slight depth in the sand deposits. But upon approaching the moraine in the central portion of the county the sand has insufficient depth to afford good water, and wells are accordingly sunk to beds of sand and gravel beneath the till.

Two wells at Surrey enter rock at about 90 feet. They are mainly through till. Several borings for gas 2 or 3 miles north of Surrey, on the edge of the sandy ridges, strike rock at 80 or 90 feet. The drift is mainly till.

On the crest of the moraine southeast of Surrey a well at Charles Coen's, sec. 12, T. 29, R. 7 W., strikes rock at 192 feet, and there obtains water. A well at William Nowel's, in the same section, strikes rock at 140 feet and obtains water at 162 feet. In both wells the drift is mainly till.

In sec. 30, T. 30, R. 6 W., on the north border of the moraine, a well at Jacob Ush's obtains water at 146 feet without striking rock. Another at George Marcum's obtains water at 130 feet. In both wells a soft till is penetrated for about 90 feet, below which is a hard till, extending to the water-bearing sand and gravel. At J. S. Williams's, a short distance north from the wells just mentioned, a well was obtained at the bottom of the soft till at a depth of 97 feet.

A well in a low, marshy tract in sec. 15, T. 30, R. 6 W., enters rock at about 75 feet.

A well on the moraine in sec. 13, T. 30, R. 5 W., penetrates 102 feet of drift, mainly blue till. Another well in the same section penetrates 80 feet. A well at Mr. Osborne's, in section 1 of the same township, has 126 feet of drift, and one at Mr. Rayburn's, in section

2,118 feet. In all these wells the water is obtained at slight depth in the underlying rock.

On the plain north of the moraine, in sec. 27, T. 31, R. 5 W., a well at James Gill's enters rock at 47 feet, after penetrating considerable till.

Passing southward near the east side of the county to the south border of the moraine, the rock is found to rise within a few feet of the surface. Wells in sec. 3, T. 29, R. 5 W., penetrate but 5 to 15 feet of drift. This region of thin drift extends southward beyond the limits of the county and westward to Rensselaer. Some of the wells obtain their water without entering the rock, but a large number are carried a few feet into the rock.

Immediately west of Rensselaer the rock surface suddenly drops down 75 or 100 feet or more, so that wells are 80 to 150 feet in drift. For example, a well on the south border of the moraine, in sec. 29, T. 29, R. 7 W., enters rock at 143 feet. A well on the plain south of the Iroquois River, in sec. 3, T. 28, R. 7 W., enters rock at about 80 feet. The rock surface continues low for several miles south from the Iroquois River, in the western part of the county, and wells are often 50 to 75 feet in depth without entering the rock.

In the southern half of T. 27, R. 7 W., the rock surface rises to a greater altitude than in the vicinity of Rensselaer. Although the general elevation is about 50 feet higher than at Rensselaer and the portion of the county east from that city, the wells in this southern end of the county often enter rock at 10 to 20 feet.

At Remington the dug wells are usually 12 to 20 feet in depth, obtaining water near the base of the drift. The drilled wells are 75 to 125 feet in depth. Robert Parker's well, 125 feet in depth, has the following section:

	Feet.
1. Drift	18
2. Shale	95 to 100
3. Solid stone, probably limestone	8 to 10
Total	125

The water rises from this depth within 18 feet of the surface. It contains sulphureted hydrogen in small amount.

Wells for water in the vicinity of Rensselaer range in depth from 30 feet to 200 feet. They enter rock at 6 to 15 feet. On the low ground along the river several of them have head sufficient to overflow, but at the general level of the town the water rises only within 5 or 6 feet of the surface. A gas-well boring at Rensselaer was carried to a depth of 1,275 feet, but the boring is not utilized, although a sulphurous water rises to the surface. This water is probably from the Lockport limestone, as in the water wells of the vicinity.

PULASKI COUNTY.

General statement.—Pulaski County is situated in the northwestern part of the State, immediately east of Jasper and south of Stark County. Its area is 430 square miles. Like Stark County, Pulaski is almost entirely occupied by sand ridges and marshes, there being only small areas of cultivable land free from sand, found chiefly on the eastern and southern borders of the county. Although it occupies the divide between the Kankakee, a tributary of the Illinois, and the Tippecanoe, a tributary of the Wabash, there is no dividing ridge, and large tracts in the northwestern part of the county might be drained with equal readiness to either stream. No adequate drainage lines have been developed in the portion of the county west from the Tippecanoe River. The portion east from the river is much better drained.

Individual wells.—In the northwestern portion of the county large areas have never been settled. On the tracts which are cultivated wells are usually obtained at 20 to 40 feet or less without reaching the bottom of the sand. In the southwestern portion of the county the drift deposits are very thin, and wells usually enter rock at 10 to 20 feet. At Medaryville, however, a well at the tile factory penetrates 92 feet of drift and obtains its water supply from the rock at 115 to 120 feet.

In the eastern part of the county wells are usually obtained at shallow depths, either in the sand or in beds of sand and gravel associated with the till.

At Winamac, the county seat, the wells often reach a depth of 50 to 60 feet. They pass through 10 to 25 feet of sand, or a sandy clay loam, below which is a bed of blue till, extending to the water-bearing gravel. The drift at this point is 110 feet in thickness. The gas-well boring, 1,200 feet in depth, obtains a flow of water estimated at 45 gallons per minute. The horizon at which the water was found has not been ascertained.

FULTON COUNTY.

General statement.—Fulton County is situated near the middle of the third tier of counties from the north boundary of the State, immediately east of Pulaski and south of Marshall County. It has an area of 380 square miles.

The surface is very diversified. In the western portion there is a till plain on which occasional drift ridges and knolls occur, and also a few sand ridges. Along the northern boundary there is the Maxinkuckee moraine, and in the eastern and southeastern portions the western slope of a bulky moraine formed by the Erie lobe, which connects in northeastern Fulton County with the Maxinkuckee moraine to form the great Erie-Saginaw interlobate moraine, which, as above noted, leads northeastward into Michigan through the northeastern

part of Indiana. West from the junction of these two moraines there is much marsh land with sandy ridges, which is imperfectly drained by southern tributaries of Tippecanoe River.

The thickness of the drift is known at Rochester, in the central portion of the county, and at Kewanna, in the western portion. At Rochester an artesian well at the court-house has 155 feet of drift, while a gas-well boring, 60 rods northeast from the court-house, has 245 feet. The altitude of the two wells is very nearly the same, and in both there are alternations of till with sand and gravel. At Kewanna the drift is 167 feet in one well and 208 feet in another. It is largely assorted material, but contains beds of blue till.

Individual wells.—Very few records of the sections of wells were obtained in this county, largely because of their shallowness. The great majority of wells are obtained at depths of 20 or 25 feet; in many cases at 12 or 14 feet. In the extreme northeast corner of the county, however, there is an area of a township or more on the east side of the Tippecanoe River where a compact till makes it necessary to sink wells to a depth of 60 or 80 feet. In one section six wells have an average depth of 70 feet. Another place in which wells are sometimes difficult to obtain is found in the northwest township of the county, in the Maxinkuckee moraine, but here it is rare for a well to exceed 60 feet in depth.

WHITLEY COUNTY.

General statement.—Whitley County is situated in the northeastern part of the State, immediately west of Allen and south of Noble County. It has an area of 330 square miles.

The extreme northwestern border of the county is occupied by the interlobate Erie-Saginaw moraine. The remaining portion of the northwest half of the county is largely occupied by the Mississinewa moraine of the Erie lobe, which closely flanks the interlobate moraine. The inner or southeastern border of the Mississinewa moraine is followed more or less closely by Eel River. The portion of the county lying east and south of Eel River is largely plane surfaced, though occasional knolls and ridges of drift give it some diversity.

This county is preeminently a clay county, there being but limited areas in which sand or gravel is found at the surface or at slight depth. The drift to a depth of 50 to 60 feet or more is usually a compact till in which only weak wells can be obtained. The most conspicuous exception is a narrow belt along Eel River, scarcely more than a mile in width, in which deposits of sand and gravel appear at the surface, and strong wells are obtained at slight depth.

The thickness of the drift is known at Columbia City, the county seat, and at Larwell, a village about 10 miles west from Columbia City. At Columbia City the gas boring made on low ground near Eel River has 224 feet of drift, mainly sand. At Larwell the gas boring

made on an elevated part of the moraine has 365 feet of drift. At this point there is about 100 feet of till at the surface, below which the drift is mainly sand and gravel. In both wells large quantities of water were obtained before reaching the rock. That at Columbia City overflows. It is probable that in the extreme southeast corner of the county the drift is less than 100 feet.

Individual wells.—But few records of wells were obtained in this county, since the sections appear to differ but little in structure. The compact till is reported in the majority of wells in every township of the county. Occasionally considerable variety is found in the distance to the water beds within the limits of a single village, but as a rule no strong wells have been obtained above the general water stratum, 50 to 75 feet below the surface.

At Churubusco, in the extreme northeast part of the county, the deepest well is reported to be 80 feet, while several are 50 feet or more.

At Collins, 4 miles southwest of Churubusco, several wells are 75 or 80 feet, through till.

At Columbia City, which is situated near the Eel River valley, wells often reach the bottom of the till at 30 or 40 feet.

The deepest water well of which record was obtained is on the plain in the southeastern part of the county, and penetrates—

	Feet.
1. Till	67
2. Sand and gravel, with beds of till	130
3. Water gravel	5
Total	202

ALLEN COUNTY.

General statement.—Allen County is situated in the northeastern part of Indiana, on the east border. Fort Wayne is its county seat. It has the distinction of being the largest county in the State, having an area of 650 square miles.

The greater part of the county has a level surface, though there are two well-defined morainic belts which pass through it. The St. Marys moraine enters in the southeast part and follows the northeast border of the St. Marys River to Fort Wayne. It then finds its continuation northward on the east side of the St. Joseph River. The Wabash moraine enters the county near Zanesville, in its southwest corner, and passes thence northward to the old lake outlet near Aboit. North from the outlet its course is northeastward along the northwest side of the St. Joseph River. There is a narrow plain in southern Allen County between these two moraines, but in northern Allen County they are separated only by the valley of the St. Joseph River. A plain in the northwestern part of the county extends beyond its limits into Dekalb and Whitley counties. The plain in the eastern part of

the county, formerly covered by the glacial lake which discharged southwestward to the Wabash, has a very smooth surface, with only an occasional low ridge of sand or bar of gravel formed by the lake waters.

In the southern half of the county the thickness of the drift is very much less than in the northern half, though probably averaging not less than 75 feet. At Fort Wayne it is 60 to 125 feet or more. Near the north border of the county the drift exceeds 200 feet, two borings having reached that depth without entering rock. In the south part of the county it is in places but 20 or 30 feet.

In this county, as in Whitley, the greater part of the drift penetrated by wells is a compact till. Wells are, as a rule, more easily obtained than in Whitley County. Along the St. Joseph River there is a narrow belt of gravelly land. There is also a gravel plain of some extent in the northwest part of the county, near Huntertown, which connects the gravel deposits of the Cedar Creek valley with the gravel belt on Eel River, thus crossing the continental divide between the St. Lawrence and the Mississippi basins. It is needless to say that there is no ridge along this part of the divide.

Individual wells.—A well at the court-house in Fort Wayne, sunk in 1875 for artesian water, reached a depth of 3,000 feet, but its head fell short several feet of coming to the surface, 772 feet above tide. The drift at this boring is 88 feet. A boring for natural gas in the old lake outlet, north of the St. Marys River in Fort Wayne, at an elevation about 750 feet above tide, penetrates 96 feet of drift. One 3 miles west, also in the lake outlet, has 90 feet of drift. The waterworks of Fort Wayne are supplied from about fifty wells, some being in gravel at depths of 40 to 60 feet, others in rock at 250 to 450 feet. Abbott's gas-well boring in the eastern part of the city, at an elevation nearly 800 feet above tide, penetrates 106 feet of drift. In this, as well as several other borings in the vicinity of Fort Wayne, the lower portion of the drift is found to contain much sand and gravel. In one boring near the bank of the Maumee River Dr. Dryer reports a flowing well, depth not given, which upon a partial analysis shows hard water, with a trace of sodium chloride and a small amount of sulphureted hydrogen; also iron carbonate in measurable amount.[1]

Wells near the county infirmary, southwest of Fort Wayne, on the border of the lake outlet, obtain water at 25 or 35 feet. After penetrating a few feet of surface sand they are mainly through till. In a few cases the wells reach a depth of 60 feet.

In the portion of the county north of the lake outlet and west of the St. Joseph River there is usually but 20 or 30 feet of till to be penetrated before a strong stream of water is found in sand or gravel. Possibly a continuous sheet of gravel underlies that region at comparatively slight depth. In one case a boring near the north line of

[1] Sixteenth Ann. Rept. Indiana Geol. Survey, p. 127.

the county, after penetrating 20 feet of surface till, was carried 125 feet into sand without reaching its bottom.

Reference was made in the discussion of Dekalb County to several wells near Spencerville which have a depth of 60 to 100 feet. Some of these are located in northern Allen County. The well at Christian Hirsh's, 198 feet deep, is very near the county line. This well, after penetrating 70 feet of till, passed through 120 feet of fine sand before entering a material coarse enough to screen. Sand of such fineness is frequently a greater obstacle to well drillers than a solid blue till free from water.

Deep wells are more common in the northeastern part of the county than elsewhere, there being a heavy sheet of till on the moraine east of the St. Joseph River and also on the old lake plain. It is not rare to penetrate till 60 or 75 feet before obtaining water.

From Fort Wayne eastward to New Haven rock is usually encountered at 80 feet or less. In some cases wells are obtained at 25 or 35 feet in beds of gravel between the sheets of till. There are also places where wells may be obtained in the sand of the old lake outlet at depths of 20 feet or less.

At the village of New Haven the wells are obtained in gravel at a depth of about 30 feet. There is, however, a well at E. W. Green's, just east of the village, situated on the upper lake beach, which has the following section:

	Feet.
1. Beach sand and gravel	9
2. Blue clay	33
3. Gravel	3
4. Blue till	23
5. Cobble and gravel	5
Total	73

Another well at Mr. Green's, 55 feet in depth, penetrates 18 feet of surface sand, and is then through blue till to the bottom. There are two wells at Herman Schuelker's, in New Haven, each about 60 feet in depth, which are mainly till. The waterworks supply at New Haven is from a gas boring 300 feet in depth. In this boring rock was struck at 82 feet. At about 150 feet a strong flow of water was obtained, which rose nearly to the surface, and at 300 feet the head was increased to 11 feet above the surface. An analysis of the water is given elsewhere.[1]

A well at Robert Bell's, east from New Haven, near the State line, strikes rock at 60 feet, and obtains water at that depth.

The southeastern portion of the county usually affords strong veins of water at convenient depths, seldom more than 30 or 40 feet. The drift in that portion of the county is probably not more than 75 feet in average thickness.

[1] Eighteenth Ann. Rept. U. S. Geol. Survey, Part IV, p. 498.

In the southwestern and southern portions of the county records of a few wells were obtained which penetrate 20 or 30 feet of till before reaching a water gravel. Occasionally a well is sunk to a depth of 75 feet, largely through till. One well on the moraine in the southwest corner of the county, 102 feet in depth, is mainly through till. Another, 85 feet in depth, is also largely through till. Upon passing eastward from the moraine in the southwest township of the county tubular wells are found to decrease in depth, being 75 or 100 feet on the moraine and but 40 or 50 feet on the bordering plain.

ADAMS COUNTY.

General statement.—Adams County is situated on the east border of the State, immediately south of Allen. Its area is 330 square miles. Like Allen County, it has a large amount of very plane surface, whose monotony is broken by two moraines, the St. Marys and the Wabash. The St. Marys moraine crosses the northeast corner of the county, and occupies a belt 2 to 4 miles in width along the east border of the St. Marys River. The Wabash moraine traverses the southern and southwestern portion of the county, following the northeast border of the Wabash River, and has a breadth seldom exceeding 2 miles. The altitude of the southern portion of the county is somewhat higher than that of the northern portion, but the general descent in the 24 miles from south to north across the county amounts to scarcely 100 feet.

The moraines and also the plain tracts present a nearly unbroken sheet of till. There appear to be no definite gravel aprons or outwash deposits from the moraines. In places where the drift is thick considerable sand and gravel is found in its lower portion, but as a rule the drift deposits are thin, their average thickness being scarcely more than 50 feet, if the deep preglacial valleys are disregarded. Wells often reach rock at but 30 or 40 feet or less, and the shallow valleys of the St. Marys and Wabash, scarcely more than 30 feet in depth, have numerous rock outcrops along their courses in this county. The great depth of valley excavation prior to the drift deposition is shown by the gas-well boring at Geneva, in the southern part of the county, where 350 feet of glacial drift was encountered. Within a mile of the boring at Geneva rock outcrops occur at an elevation as high as the well mouth. Notwithstanding the great depth of these preglacial valleys, they are so completely filled that no surface indications of their courses can be seen.

Individual wells.—Along the St. Marys moraine and the plain east of it, in the northeastern part of the county, the depth of wells ranges from 20 to 50 feet, mainly through till.

At Decatur rock is struck at the court-house well at 40 feet. It penetrates till, with the exception of a few feet of sand at the bottom. Several wells in the city obtain their water supply from this bed of

sand and gravel above the rock. The city waterworks obtain a supply from limestone at 250 feet.

At Pleasant Mills, near the east border of the county, wells are 20 to 35 feet in depth, mainly through till. They usually obtain water in a bed of sand or gravel, but a few enter the rock.

On the plain south and west from the St. Marys River records of several wells were obtained which enter rock at 50 or 60 feet. They usually penetrate from 35 to 50 feet of till, beneath which a bed of sand is found, which, if not of too fine texture, is made the source of water supply, but if very fine it is cased out, and water is obtained from the underlying rock. On portions of this plain rock is encountered at 20 to 25 feet.

On the Wabash moraine, in the southern part of the county, records of two wells were obtained in sec. 32, T. 25, R. 15 E., which enter rock at 51 and 60 feet. They each penetrate 35 or 40 feet of till, below which is sand. A well on the moraine in section 31 of the same township enters rock at 70 feet. It penetrates till 52 feet, below which is sand and gravel.

Along the Wabash River wells are usually obtained at 15 or 20 feet, either at the surface of the rock or at slight depth in it.

At Geneva, which is situated near the Wabash River, the wells usually obtain water in gravel below till at about 35 feet. A few are sunk into limestone and have a depth of 80 feet. The gas-well boring, as above noted, penetrated 350 feet of drift. Of this, the upper 80 feet was principally till; the remaining 270 feet was mainly sand and gravel.

On the plain southwest from the Wabash River rock is usually encountered at but 20 or 30 feet. The majority of wells, however, are obtained without penetrating the rock.

WELLS COUNTY.

General statement.—Wells County is situated immediately west of Adams and south of Allen County, in the northeastern part of the State. It has an area of 357 square miles. Its topography is quite similar to that of Adams County, there being a plain surface except in two moraines, one of which crosses the northeastern portion of the county and the other the southwestern. The one in the northeastern part is the continuation of the Wabash moraine of Adams County. It follows the northeastern border of Wabash River to about the middle of the county, where it turns north away from the river and traverses Allen County, as noted above. The moraine which crosses the southwestern corner follows the northeast border of Salamonie River and receives the name Salamonie from that stream. Neither of these moraines much exceed 2 miles in average width in their course through this county. There is also a slight ridging of the drift along

the northeast border of Rock Creek, parallel to and midway between the two moraines just mentioned. Its relief is, however, but 15 or 20 feet, or scarcely half as great as the relief of either of the moraines mentioned. The streams of this county, like those of Adams, are flowing in small, shallow valleys, cut but 20 to 40 feet into the plains.

The drift is very similar to that of Adams County, being a somewhat uniform sheet of compact till at surface, with thin beds of sand included in or underlying it. The thickness of the drift is also moderate, rock being struck at many places at 30 to 50 feet, and occasionally at less depths. The average thickness for the county, unless greatly affected by concealed deep valleys, probably does not exceed 50 feet. There are no surface indications of deep valleys traversing the county, nor have borings shown their presence. The deep borings, however, are not sufficiently numerous to afford much knowledge of the topography of the rock surface.

Individual wells.—Wells along the Wabash moraine, in the north part of the county, usually penetrate but 50 or 75 feet of till, and tubular wells are usually put down to these depths. The dug wells obtain moderate amounts of water from local beds of gravel or sand in the till at much less depth. At Kingsland, on the crest of the moraine, a record of one well was obtained, which enters rock at 80 feet, but another well of the same depth does not reach rock; both are mainly through till.

West of the Wabash moraine rock is usually found at 50 to 70 feet, while in the vicinity of Uniondale it is struck at 20 to 40 feet. The tubular wells often enter the rock. Dug wells usually obtain supplies of water in the lower portion of the drift.

Near the eastern border of the county the drift on the moraine is about 100 feet in thickness, and several wells in that vicinity are 60 to 100 feet in depth. On the plain north of the moraine wells are usually obtained at less than 50 feet.

Along the Wabash River there are numerous outcrops of rock, but wells are ordinarily obtained above the rock at depths of 20 feet or less.

At the city of Bluffton, the county seat, the supply for the waterworks is obtained from wells drilled into the rock to a distance of 150 to 300 feet.

On the plain southwest from the Wabash River wells are usually obtained at 40 feet or less in beds of sand or gravel below the till. Occasionally a well is sunk to a depth of 60 or 75 feet.

On the Salamonie moraine the wells range from 20 feet up to 75 feet or more. They are principally through till.

Along the Salamonie River, and on the plain west of the river, wells are seldom more than 30 feet in depth, and are usually through till to the water vein near the bottom.

HUNTINGTON COUNTY.

General statement.—Huntington County is situated in northeastern Indiana, west of Wells and the southern portion of Allen County, and has an area of 380 square miles. Huntington is its county seat. The greater part of this county is a smooth, sloping plain, standing 800 to 900 feet above tide. The Salamonie moraine, which enters it from Wells County in the southeastern corner, becomes scarcely traceable near the center of the county, and no other moraine of prominence is found within the limits of the county. The valleys are small, with one exception, that of the lake outlet, which joins the Wabash at Huntington. This outlet has a depth of 40 to 75 feet and a breadth of 1 to 2 miles throughout its course in the county, whereas the Wabash, above its junction with the outlet, and also the Salamonie, have valleys scarcely one-eighth of a mile in average width and of less depth than the lake outlet.

The elevation of the rock surface decreases gradually northward from the southern boundary of the county to the lake outlet. North of the lake outlet it appears to drop down rapidly. The drift is comparatively thin in the portion of the county south of the outlet, there being seldom so much as 100 feet encountered in wells. North from the outlet the thickness of drift is 150 to 200 feet or more.

In Huntington County, as in Wells and Adams, the drift is mainly a compact till. Wells are obtained either in local deposits of gravel and sand within the till or more extensive deposits which appear to prevail near the base of the drift.

Individual wells.—Wells on the plain north of the Wabash outlet have, in a few cases, entered rock at about 140 feet after penetrating a nearly solid sheet of till. Ordinarily, the wells are but 50 to 100 feet and encounter no rock.

In the city of Huntington, on the uplands bordering the lake outlet, wells are frequently obtained at about 30 feet in gravel below till. Along the outlet they are usually sunk into the limestone, which there outcrops quite extensively. The waterworks wells are sunk into the limestone to a depth of about 100 feet. Although there are 11 wells in use, the supply is insufficient and some water is pumped from the river.

Above Huntington, in the vicinity of Roanoke, wells in the old lake outlet are often obtained without entering rock, at depths of 10 to 25 feet. One well near Roanoke enters rock at 36 feet.

In the vicinity of New Lancaster, on the borders of the Salamonie River, gravel is more abundant than elsewhere along the valley and wells often obtain water without penetrating till. Between New Lancaster and Andrews wells commonly penetrate 20 to 40 feet of till.

At Andrews, the wells are usually carried into the limestone to depths of 60 to 150 feet, and occasionally to over 200 feet. The analy-

sis of water from a well in this village, 214 feet in depth, is given elsewhere.[1] The water is shown to be slightly saline as well as hard. It also contains much sulphureted hydrogen.

In the vicinity of Warren several flowing wells have been obtained in limestone on low ground along the Salamonie River at a depth of 65 to 100 feet. The head is sufficient to carry the water only 5 or 6 feet above the surface. The water is decidedly chalybeate.

WABASH COUNTY.

General statement.—Wabash County is situated in the north-central portion of the State, with the city of Wabash as its county seat. Its area is 430 square miles. The eastern border of the county is occupied throughout its entire length by the Mississinewa moraine. The northwestern part of the county is occupied by the Erie-Saginaw interlobate moraine, the southeast border of that moraine being near the valley of Eel River. The portion of the county west and south from these moraines is a till plain. The morainic ridge on the east border of the county, as well as the interlobate moraine, rises above the 800-foot contour, but the greater part of the plain in the county falls below 800 feet, and on the immediate border of the Wabash scarcely exceeds 700 feet. The valley of the Wabash passes through the county a little south of the center. Occupied as it was by the lake outlet, it is very much larger than the other valleys of the county and the valleys of similar-sized streams in the newer drift area. The average width is fully 1 mile and the depth 50 to 100 feet.

In Wabash County, as in Huntington, the general elevation of the rock surface is much higher south from the Wabash River than it is north, and as the altitude of the northern portion is fully as great as that of the southern, the drift deposits of the northern portion are very heavy. The drift of the southern portion is about like that of counties to the east and probably falls below an average of 100 feet. The drift in the northern portion probably in places exceeds 300 feet, the thickness at North Manchester, in Eel River Valley, being 274 feet. In the southern portion, however, there are valleys deeply filled with drift that show a rock surface about as low as that of the northern portion of the county. Such a valley was brought to light by the boring at Lafontaine (Ashland post-office), where the drift is found to be 300 feet in thickness.

Wabash County resembles the counties to the east in carrying a somewhat uniform sheet of compact till. The only gravelly districts worthy of note are a narrow belt along the borders of Eel River and terraces in the valley of the Wabash.

Individual wells.—A boring for natural gas at North Manchester penetrates 274 feet of drift, mainly sand. The drift within the limits

[1] Eighteenth Ann. Rept. U. S. Geol. Survey, Part IV, p. 498.

of that village, however, varies considerably. Several flowing wells along Eel River valley penetrate till to a depth of 50 to 70 feet, beneath which is a sheet of water with a head sufficient to rise 10 or 12 feet above the surface. The waterworks supply is from flowing wells 100 feet in depth. In the higher portion of the village wells are ordinarily obtained at 30 or 35 feet, without penetrating much till, but in a few instances they are carried to depths of 100 or 115 feet, largely through till.

On the Mississinewa moraine, east and southeast from North Manchester, wells are often in till to a depth of 100 feet or more before obtaining a strong vein of water. One well, 4 miles east of North Manchester (in sec. 12, T. 29, R. 7 E.), penetrated 156 feet of till.

On the plain between Eel River and the Wabash and west from the Mississinewa moraine wells usually penetrate till to a depth of 30 or 40 feet to obtain a strong vein of water. On the north side of Eel River, west from North Manchester, the interlobate moraine usually presents 50 feet or more of compact till at its surface, through which many wells have been sunk.

At Laketon, in the valley of Eel River, below North Manchester, a well 125 feet in depth is mainly through sand. It is thought by the residents of that village that the sheet of sand passes northward beneath the till of the moraine, but there have been few deep wells to test the value of this opinion.

At the city of Wabash wells are often obtained in the valley at depths of 15 to 25 feet without reaching the bottom of the gravel. A better supply is, however, obtained at about 100 feet in the limestone. Some objection is offered to the water from the limestone because of its extreme hardness. For that reason the waterworks are supplied largely from drift wells. The wells are located in the valley of Treaty Creek, south of the city, and are overflowing. The depths range from 42 to 55 feet.

On the Mississinewa moraine, south of the Wabash, several wells have been put down to depths of 95 or 100 feet or more through till before obtaining an adequate supply of water, but as a rule water may be obtained at less than 50 feet.

On the plain west of the Mississinewa moraine, in southern Wabash County, till is usually penetrated to a depth of 25 to 40 feet or more.

At Lafontaine, in the south part of the county, the gas boring penetrates 300 feet of drift, but rock outcrops within a short distance, both above and below Lafontaine, in the bluffs of the Mississinewa River. Wells are usually obtained at Lafontaine and at other points along the Mississinewa, in the southern part of the county, at depths of 25 or 35 feet. Gas borings in the vicinity of Somerset, in the southwest corner of the county, show the drift to have a thickness ranging from 35 up to about 100 feet the lower portion of which is a water-bearing sand or gravel.

In the Seventeenth Report of the Indiana Geological Survey many records of wells are published which have a depth of only 10 to 40 feet. With these are occasional records of deeper wells. One near New Madison (sec. 11, T. 29, R. 7 E.), 207 feet in depth, strikes limestone at 181 feet. It penetrates till 160 feet, below which is 21 feet of sand. Two other wells in section 26 of the same township penetrate a similar amount of till, and obtain water in sand or gravel at 164 and 185 feet without entering rock.

It is stated that wells occasionally enter rock at 70 or 75 feet on farms 5 miles north of Lagro, but a well in that vicinity, on the farm of Christopher Speicher, strikes no rock at a depth of 156 feet. It is mainly through blue till, there being a thin bed of gravel at 80 to 84 feet and another at 150 to 156 feet.

Records of two deep wells in the southwest township of the county are reported as follows: On farm of Jacob Thomas, depth 64 feet, till except 4 feet of water-bearing gravel at bottom; on farm of L. Waggoner, depth 96 feet, till 80 feet, below which are alternations of gravel, sand, and blue mud, to a limestone at bottom.

On the farm of John H. Pefley, near the south bluff of the Wabash River, in sec. 18, T. 27, R. 8 E., a well 62 feet in depth is reported to have barometric properties of a marked character, there being an inrush of air in fair weather and an escape of air in foul weather. A whistle, made of two convex disks with a hole in the center, attached to a gas pipe screwed into the base plate of the pump may be heard frequently at the distance of one-half mile, and makes apparent the force of the current of air. It is probable that air spaces in the sand offer a medium for the inflow of air to correspond with the changes of atmosphere outside the well. The section of the well is as follows:

	Feet.
1. Soil and yellow clay	7
2. Sandy blue clay	24
3. Blue hardpan clay	1½
4. Dry sand	8
5. Sandy blue hardpan	12
6. Water-bearing blue hardpan	9½
Total	62

MIAMI COUNTY.

General statement.—Miami County is situated in the north-central part of the State, immediately west of Wabash County, with Peru as its county seat. Its area is 360 square miles. The broad Wabash Valley traverses it nearly centrally from east to west and, as in Wabash County, separates a district of thin drift on the south from one of thick drift on the north. The northern portion is even more elevated than the southern, but the rock surface is much lower in the former district. The portion of the county south of the Wabash is

nearly all plane surfaced, and so, also, is much of the district between the Wabash and Eel rivers. That north of Eel River is strongly morainic, and embraces part of the large Erie moraine, which, with the Maxinkuckee moraine of the Saginaw lobe, forms the interlobate moraine of northeastern Indiana and southeastern Michigan. The drift is composed largely of till in the plains, but in the moraines there are knolls of gravel and sand associated with the till knolls, as well as extensive deposits of sand and gravel in the deeper portion of the drift.

Individual wells.—A gas boring 2½ miles north of Peru penetrates 318 feet of drift, a large part of which is water-bearing sand and gravel. Neighboring wells for water usually obtain an abundant supply after penetrating till 30 to 40 feet. One well, however, in sec. 29, T. 28, R. 5 E., penetrated 90 feet of till before obtaining water.

In the city of Peru there are few wells drilled into rock, although there are numerous rock outcrops in the vicinity of the city. The average depth of the wells is about 30 feet, with a range from 15 up to 60 feet. They penetrate either a loose alluvial deposit before entering gravel and sand or pass immediately into gravel and sand. There is, therefore, a liability of contamination of the water from cesspools or other sources. The city water supply is pumped from the Wabash River.

At Bunker Hill a sheet of till 25 to 40 feet in thickness is usually passed through before water-bearing sand or gravel is reached. In one of the gas wells at Bunker Hill the drift was 68 feet, in another 84 feet; in both the lower half was largely sand and gravel.

A gas boring east of Bunker Hill, in sec. 21, T. 26, R. 5 E., at an altitude of 175 feet above the Wabash at Peru, penetrates 60 feet of drift, of which 54 feet is till and the lower 6 feet gravel.

At Amboy the wells penetrate about 15 feet of till, beneath which is a water-bearing gravel extending to the rock. In that vicinity rock is struck at 35 to 50 feet.

At Xenia (Converse post-office) the dug wells are 10 to 20 feet in depth, in gravel beneath a sheet of till. The drift in that vicinity is variable in depth, ranging from 25 up to 100 feet or more in thickness. A few wells are drilled into the rock to depths ranging from 100 to 400 feet. From the deep wells the head is sufficient to bring to the surface water which is reported to be of excellent quality.

In the southwestern part of the county wells are often 50 to 70 feet through till, though shallower wells are usually obtained.

A well at Denver, in the northern part of the county, is noted by Mr. Gorby,[1] which penetrates 125 feet of sand and gravel and reaches no rock.

[1] Sixteenth Ann. Rept. Indiana Geol. Survey, p. 173.

CASS COUNTY.

General statement.—Cass County is situated in the north-central part of the State, the city of Logansport being its county seat. Its area is 420 square miles. The valley of the Wabash traverses it nearly centrally from east to west. The portion south of the Wabash is a comparatively smooth till plain. The portion north of the Wabash is largely morainic, though there is a plain in the extreme northwest corner of the county. There is not the conspicuous descent of the rock surface from south to north that appears in the three counties along the Wabash east from this county. In the immediate vicinity of the Wabash the drift is thin, but on the upland, both north and south of the river, a thickness of 75 to 100 feet or more is found. The drift is very largely till, as in counties to the east.

Individual wells.—At Royal Center, in the northwest part of the county, the oil-well borings enter rock at about 110 feet. The water wells are about 40 feet, though having a range from 15 up to 110 feet. They usually penetrate the following series:

	Feet.
1. Surface clay	4 to 6
2. Gravel	5
3. Blue till, extending to the water-bearing gravel	40
Total	50

At Logansport wells range in depth from 12 to 80 feet, but the majority are about 40 feet. The rock surface being uneven, wells in some cases reach a depth of 40 feet in drift, while in others they enter limestone at 10 or 20 feet. The drift in this city being composed mainly of gravel and the water surface being but a few feet below the well mouth, there is much danger of contamination. The city waterworks obtain the supply in part from springs and in part from Eel River.

On the Wabash bluff, south from Logansport, wells are about 40 feet in depth, the upper half being through till and the lower in gravel.

A well on the north bluff of Wabash River, near Logansport, sec. 27, T. 27, R. 2 E., was largely through sand and gravel to a depth of 90 feet, and struck wood and leaves near the bottom.

In the vicinity of Lake Cicott, in the western part of the county, there are sand deposits on the north bluff of the Wabash which in some cases afford water for wells at a depth of 15 feet. Wells usually, however, penetrate the underlying till.

At Walton, in the southeastern part of the county, the drift is about 80 feet, and is largely till. At Galveston the drift in a valley 20 feet or more below the level of the railway station is shown by a gas boring to be 41 feet in thickness. The lower portion contains much water.

WHITE COUNTY.

General statement.—White County is situated in the northwestern part of the State, immediately west of Cass County, its county seat being Monticello. It has an area of 500 square miles. With the exception of a few drift ridges in its southern portion and occasional sand ridges in its northern portion, it has a plane surface. The drift ridges are most conspicuous immediately east of Chalmers. It is at this point that the large Erie moraine, which has been referred to as occupying the northern portion of Miami and Cass counties, makes a curve to the south. A smaller and perhaps older moraine, formed probably by the Saginaw lobe, leads from near Chalmers westward through White and Benton counties. The Tippecanoe valley in its course across White County deepens from a comparatively shallow ditch near the north border of the county to a trench 75 or 100 feet in depth at the south. Its breadth is but a few rods greater than the stream, and is in strong contrast with the large valley of the Wabash, into which it discharges.

The drift in the northwestern portion of this county, like that of adjacent portions of Pulaski and Jasper counties, is very thin, and the majority of wells enter rock at 10 to 20 feet, or even less. In the southeastern portion of the county there is a heavy deposit of drift, 200 feet or more in thickness.

Individual wells.—At Monon, in the north part of the county, rock is entered at from 3 to 30 feet. Wells are usually about 40 feet, though they range from 20 to 200 feet in depth. The limestone from which the water is obtained contains a sufficient amount of iron pyrites to affect the water appreciably, though not sufficient to render it unfit for drinking.

At Monticello, the county seat, wells are usually obtained at 20 or 30 feet, in gravel below till. Tubular wells are somewhat deeper, the deepest being about 140 feet. The city water supply comes from a large well of moderate depth, but thought to be beyond the reach of surface contamination. The gas-well boring at this place penetrated 205 feet of drift, largely till.

At Reynolds, in the central portion of the county, there are a series of sand ridges, in which water is often obtained at a depth of 15 or 20 feet, or even less. Tubular wells reach a depth of 75 to 120 feet without entering rock. One of the tubular wells, at Mr. Van Voorst's, 56 feet in depth, is reported to have entered a black muck at the base of the sand, about 30 feet from the surface, 6 or 7 feet in thickness, beneath which is a blue clay about 15 feet thick, extending to the water-bearing gravel at bottom. A well opposite the post-office found a similar muck at the bottom of the sand at 20 feet, and entered gravel beneath it at 25 feet. Wells not infrequently encounter muck below the sand in this region. A well in the south part of Reynolds, 120

feet in depth, encountered either a bowlder or a rock ledge, which prevented further boring.

Among the deepest wells in the county is William Owen's, about 6 miles southwest of Reynolds, 190 feet in depth. It entered rock at 30 feet. Inflammable gas was found at about 145 feet. Wells in that vicinity often strike rock at 20 or 30 feet. The thick drift seems to set in immediately east from a line running south from Reynolds through Chalmers. In Chalmers rock is struck at about 90 feet, but at Albert Gosley's, 1½ miles east of Chalmers, no rock was found at 150 feet; and a well at J. N. Bunnell's, a mile southeast of Reynolds, strikes no rock at 160 feet.

On the drift ridge west from Chalmers rock is usually struck at 75 or 80 feet. On the plain north of the ridge it is struck at 20 to 40 feet. On the south slope of the ridge, in sec. 5, T. 25, R. 5 W., rock is struck at 54 feet and water obtained at 75 feet. One well, however, on the moraine near the west line of the county, failed to reach rock at 113 feet. The drift, both on the plain and in the morainic ridges in the southern part of White County, appears to be mainly till.

BENTON COUNTY.

General statement.—Benton County is situated on the western border of the State, immediately south of Newton and Jasper counties and west from White County. It has an area of 503 square miles, and the village of Fowler is its county seat.

This county is occupied by several somewhat prominent drift ridges. In the north tier of townships there is a sharp drift ridge, scarcely a mile in average width, but 25 to 75 feet in height, passing entirely across the county and forming the south border of a plain which is drained by the Iroquois River. A few miles farther south a prominent ridge enters Benton County from the west and passes eastward, bearing slightly north, to the village of Fowler, where it abruptly terminates. This ridge has a breadth of 3 or 4 miles and a relief of 60 to 75 feet or more above bordering plains. On the south border of the county is a third ridge, which passes eastward to the vicinity of Oxford, where it swings abruptly to the north and terminates immediately east of Fowler. This ridge has about the same breadth as the one north of it, but scarcely so great relief. Aside from the three main ridges just mentioned, there are, northwest from Fowler, a series of sharp drift knolls, 25 to 50 feet in height, filling a portion of the plain between the north and middle ridges. Notwithstanding the occurrence of several prominent ridges, the general elevation of the county is remarkably uniform, the variations in elevation being about that of the relief of the ridges. Nearly the entire county lies between the contours of 700 and 800 feet above tide. A point near Fowler, on a sharp gravel knoll, reaches 857 feet, said to be the highest in the county.

The thickness of the drift in this county is found to be very great in the southern and western portions, in one place exceeding 400 feet. But in the northern and eastern portions of the county, including nearly half its area, the drift is seldom found to exceed 100 feet. The surface portion of the drift appears to be generally a compact till, but the deeper portions, so far as tested by well borings, consist mainly of sand and gravel.

Individual wells.—The following list of well sections includes several which have already been published,[1] but the majority were personally obtained from well drillers or owners of wells.

The drift in northwestern Benton County, north from Sugar Creek, is shown by several wells to be a compact till to considerable depth, but along Sugar Creek and on the plain to the south much sand is encountered.

At Earl Park a well, bored by P. M. Crane, penetrates—

	Feet.
1. Soil and yellow till	18
2. Blue till	40
3. Fine gray quicksand	20
4. Blue till	12
5. Limestone	12
Total	102

The water supply is from the limestone. At Raub's warehouse, in Earl Park, limestone was struck at 80 feet, and water obtained at 110 feet. The drift was entirely till. Rock is quarried on Sugar Creek, 1 mile north of Earl Park, on ground but 40 to 50 feet lower.

In sec. 1, T. 26, R. 9 W., near the north line of the county, Mr. Schlautenhofer has a well 108 feet in depth, which obtained water at that depth beneath a bed of dark material thought to be coal. Shale was struck at 70 feet.

In sec. 7, T. 26, R. 8 W., a well 109 feet in depth has the following section:

	Feet.
1. Soil and yellow clay	6
2. Blue clay	44
3. Sand	2
4. Blue clay	57
Total	109

Other wells on the same section are obtained at 35 or 40 feet in a bed of gravel beneath the blue clay.

On Mr. Raub's farm, 2 miles east of Earl Park, water is obtained in limestone at 54 feet. The drift, 50 feet, is entirely till.

On the crest of the north drift ridge, in sec. 20, T. 26, R. 7 W., Mr. J. W. Swan has a well 116 feet in depth, which is thought to have struck sandstone at 82 feet, though it is reported to obtain water from gravel

[1] Fifteenth Ann. Rept. Indiana Geol. Survey, pp. 205-220.

at the bottom. The drift was till to a depth of 75 feet. Another well, only 150 yards distant, penetrated till to a depth of 82 feet without entering rock. On the south slope of the moraine Mr. Swan made a well which obtained water beneath the till at 25 to 27 feet. Another well on the south slope penetrated beds as follows:

	Feet.
1. Till	21
2. Cemented gravel	10
3. Water gravel	3
Total	34

Two miles east from Mr. Swan's, in the western edge of Gilboa Township, a well on the moraine strikes rock at 173 feet. It is reported to be mainly blue till with occasional beds of sand. Water was obtained at a depth of 196 feet. There is a quarry on Pine Creek, just south of this moraine, in sec. 28, T. 26, R. 7 W., at an elevation perhaps 75 feet lower than the well mouth. The rock surface, therefore, varies about 100 feet in elevation.

In the eastern part of the county several wells enter rock at 50 feet or less, and there is a quarry on Pine Creek just north of the village of Aydelott.

A well near the northern terminus of the southernmost of the three ridges above mentioned, in sec. 15, T. 25, R. 7 W., enters rock at 55 feet and obtains water at 60 feet. Another well, in sec. 10 of the same township, 85 feet in depth, enters rock at 72 feet. In both wells the drift is a compact blue till.

At Fowler the waterworks' supply is obtained from wells about 175 feet in depth. They enter rock at 130 feet. The water rises within 25 feet of the surface and the wells are estimated to yield 150 gallons per minute. Several other deep wells have been made in Fowler and vicinity, which show a considerable variation in the elevation of the rock surface. A well at Mr. Van Nata's, in the west edge of the village, enters rock at 91 feet, after penetrating a nearly solid bed of till. A neighboring well, bored by Mr. Fowler, only 300 yards distant, reached a depth of 150 feet without encountering rock. In this well the upper 100 feet is till, below which is gravel and sand. The well at the post-office in Fowler strikes no rock at 160 feet. The drift is reported to be mainly sand. At the Tremont Hotel a well 104 feet in depth strikes no rock and is mainly through sand. The gas-well boring in Fowler, one-fourth mile north of the railway station, strikes rock at 158 feet. In all these wells the surface altitude is very uniform, there being scarcely 10 feet variation. Wells for a short distance north and east of Fowler are obtained at 20 to 30 feet in sand and gravel below till.

On the farm of Mrs. Sumner, at Sugar Grove, 6 miles southwest of Earl Park, rock is struck at 41 feet and water obtained at 47 feet.

A few miles southwest of Fowler, on the middle drift ridge noted

above, several deep wells have been made. Mr. William Bennett, sec. 33, T. 25, R. 9 W., has had several wells sunk to a depth of about 150 feet, and one to a depth of 264 feet, without reaching rock. The drift is mainly till to a depth of 150 feet, below which is sand. The following section is from the well at Mr. Bennett's residence:

	Feet.
1. Soil and yellow till	20
2. Blue till	27
3. Hard gray till	12
4. Greenish-gray till	81
5. Fine gravel	4
6. Greenish till	18
7. Coarse gravel, with water	8
Total	170

A well at Lawrence Broes's, sec. 4, T. 24, R. 9 W., 260 feet in depth encounters no rock, and has a section similar to Mr. Bennett's. A well 3 miles north of Ambia, on the crest of the moraine, penetrates—

	Feet.
1. Yellow till	14
2. Blue till	80
3. Fine, dry sand	20
4. Blue till	46
5. Gravel, with water	1 to 2
Depth to water	160

At John Shilling's, 4 miles northeast of Ambia, near south border of the moraine, a well 114 feet in depth penetrates—

	Feet.
1. Soil and sand	28
2. Blue till	50
3. Quicksand	16
4. Blue till	20
Gravel at bottom.	
Total	114

Wells along the south border of the middle ridge are usually obtained at shallow depths, but occasionally reach a depth of 50 to 65 feet. They often encounter sand and gravel near the surface. Thus, at James Siddon's well, about 2 miles north of Talbot, the drift is mainly sand to a depth of 24 feet, below which there is a bed of blue till 40 feet in thickness, water being obtained in gravel at 65 feet. Another illustration is found in the well at Mr. A. K. Dill's, 3 miles north of Boswell. This well penetrates a loose gravel 18 feet, below which is a thin bed of blue clay, which in turn is underlain by a cemented gravel 40 to 45 feet in thickness, extending to the water gravel at 65 feet.

In the southern tier of townships several borings have been made which show 300 to 400 feet of drift. At Otterbein, however, a boring 212 feet in depth strikes rock at 132 feet, and about 5 miles north of

Otterbein rock is struck at 80 feet. Among the borings showing a large amount of drift are the following:

W. J. Templeton's boring for artesian water, about three-fourths of a mile northeast of Templeton, reached a depth of 300 feet without entering rock. The drift is mainly till, but sand in its lower part furnishes water, which rises nearly to the surface, 675 feet above tide.

A boring by W. J. and L. Templeton, on their farm in sec. 32, T. 24, R. 8 W., about 5 miles southwest of Oxford, made with a view to obtaining coal, penetrated 372 feet of drift, as follows:

	Feet.
1. Yellow till	12
2. Blue till	115
3. Cemented gravel	25
4. Yellow till and gravel	110
5. Black material, called shale	10
6. Clay and sand	100
Total	372

The well was continued to a depth of 537 feet, or 165 feet into the rock, which is mainly limestone.

A boring for gas on Joseph Atkinson's farm, about 1 mile east of the Templeton well, penetrated 410 feet of drift. A small amount of gas was found in the drift at a depth of 40 feet.

A well in the village of Talbot, 310 feet in depth, strikes no rock; the upper 60 feet is till, the remainder mainly sand.

In addition to the borings showing a very deep drift there are several others worthy of note in this southern tier of townships. A well made by W. J. Templeton, 2 miles east of Templeton, 177 feet in depth, penetrates—

	Feet.
1. Yellow till	12
2. Blue till, with thin sand beds	75
3. Cemented gravel	20
4. Yellow clay and sand	70
Total	177

J. D. Stengle's well at Templeton penetrates 60 feet of till, beneath which is water-bearing sand. Depth of well 80 feet. A well 2 miles south of Boswell penetrates—

	Feet.
1. Yellow till	13
2. Blue till	34
3. Quicksand	20
4. Gravel	66
Total	133

A well on Samuel Dove's farm, immediately east of Boswell, 185 feet in depth, strikes no rock.

At the several villages along the Lake Erie and Western Railroad wells are usually obtained at 20 feet or less, but, as indicated above,

occasional wells are much deeper. Many wells in Templeton obtain water at 20 or 30 feet. They enter blue till at about 6 or 8 feet. At Oxford wells are usually but 14 to 20 feet in depth, though occasionally 80 or 90 feet. In the east part of the village a flowing well has been obtained at a depth of 55 feet. It has a head about 5 feet above the surface. The water is strongly chalybeate. At Ambia, records of two wells were obtained which slightly exceed 100 feet in depth. They are mainly through blue till.

WARREN COUNTY.

General statement.—Warren County is situated on the west border of the State, immediately north of the Wabash River, with Williamsport as its county seat. It has an area of 360 square miles.

Like Benton County, which borders it on the north, this county is traversed by several conspicuous ridges of drift. Along its northern border is the southernmost of the ridges described in the account of Benton County. It has a breadth of 2 or 3 miles and a relief above the plain on the south of 40 to 50 feet or more. A few miles southeast of this ridge is a larger one, which enters the State near State Line village, passes northeastward nearly to Williamsport, and there turns north along the west side of Pine Creek. This ridge is 3 to 6 miles in width and has a relief of 30 to 60 feet or more above bordering plains on the north and south. East from Pine Creek are two ridges trending from northwest to southeast, extending from the valley of the creek to the valley of the Wabash, a distance of 8 or 10 miles. They are each a mile or more in width, and stand 30 or 40 feet above the bordering plains. The narrow plain between them is scarcely 1 mile in average width. The extreme northeastern part of the county is a plain. It is estimated that fully one-half the area of the county is occupied by the drift ridges.

The surface portion of the drift throughout the county is usually a compact till, though the portion east from Pine Creek becomes gravelly in limited areas. Along the Wabash there are conspicuous gravel terraces below Williamsport. Above that city the valley is too narrow for extensive development of terraces. The narrowness is due to the resistant rock strata in which the stream has cut its passage. It is, however, seldom less than one-half mile in width.

For some distance north from the Wabash, unless it be at the extreme eastern border of the county, rock is encountered at comparatively slight depth, seldom more than 100 feet; but along the northern border of the county it is probable that the drift, like that of the adjoining portion of Benton County, is 300 to 400 feet or more in thickness.

Individual wells.—But few well records have been obtained in this county, owing partly to the fact that wells are generally obtained at comparatively slight depth.

At Williamsport, the county seat, wells vary greatly in depth, there

being a range from 14 feet up to about 100 feet. In a portion of the city rock is struck at 10 to 15 feet, but there are places where the drift attains a thickness of 85 feet. A boring for gas at this city 1,540 feet in depth found fresh water at a depth of 65 feet in great quantity; also at about 165 feet. From the latter depth water rises within 32 feet of the surface. Salt water was struck at about 1,200 feet. Gas not being obtained, the salt water was shut off, and the fresh water is thus available for water supply. The well is estimated to yield 20 gallons per minute.

On the Wabash terrace below Williamsport, which stands about 100 to 110 feet above the river, several wells have been sunk to the level of low water in the river. They are through gravel or sand their entire depth. The water rises and falls with the rise and fall of the river.

A boring for coal at West Lebanon penetrated a soil containing wood and leaves beneath the blue till at a depth of 140 feet. Rock was entered a short distance beneath this soil. About a mile southeast from West Lebanon, on ground nearly 100 feet higher, rock is struck at a depth of only 60 feet.

TIPPECANOE COUNTY.

General statement.—Tippecanoe County is situated somewhat north of the middle of the western part of the State, with Lafayette, the county seat, near its geographic center. It has an area of 500 square miles. The greater part of the surface is plain or but gently undulating. There are, however, in the southern half a number of sharp gravelly knolls and ridges, which in places constitute a nearly continuous belt. The most conspicuous one, known as High Gap Ridge, leads from Culver Station westward past Taylor and West Point to the vicinity of the Fountain County line. It is, however, less than a mile in width, and the height of the ridges and knolls seldom exceeds 50 feet. The most conspicuous topographic feature of the county is the troughlike valley traversed by the Wabash River. The valley proper has a depth of more than 100 feet. From its borders there is a gradual rise both to the northwest and southeast—to an altitude in the northwest more than 200 feet above the river, and in the southeast to fully 300 feet.

With the exception of the sharp gravelly knolls referred to above, the surface portion of the drift is composed largely of compact till. The wells of the county usually find water at convenient depths, seldom penetrating so much as 80 feet. The lower portion of the drift, so far as tested by deep borings and by exposures along the Wabash and its tributaries, is largely sand and gravel.

The thickness of the drift varies greatly, partly because of difference in surface elevation, but more largely because of inequalities of the underlying rock surface. In the western part of the county, in

the vicinity of the Wabash River, rock ledges rise to a height of 50 to 100 feet or more above the stream, and are well exposed on Flint Creek and Indian Creek. In the northeastern part of the county, also, there are rock exposures on the borders of the Wabash and the lower course of Sugar Creek. Between these exposures, occupying the central portion of the county, there is a deeply filled basin, with drift 300 feet or more in thickness. This appears to be part of a great valley or trough which leads westward across southern Benton County.

To sustain the view that a deeply filled valley extends westward across northern Tippecanoe County, two well sections in the northwestern part of the county are cited. One, in sec. 26, T. 24, R. 6 W., reaches a depth of 176 feet without encountering rock; another, in sec. 18, T. 24, R. 5 W., strikes no rock at a depth of 126 feet. Toward the south, near the Wabash River, the rock appears in valleys of streams at a higher level than the botton of these wells. Passing northward into White County the rock appears at higher level than at these wells. It seems probable that the deepest portion of the valley passes near Dayton and Lafayette and thence north of west across the northwest part of the county, beyond which it finds its continuation westward through southern Benton County.

Along the valley of the Wabash there are gravel terraces reaching a height of nearly 100 feet above the stream. The most conspicuous are located below Lafayette, where they receive the name Wea Plain. They are also conspicuous in the vicinity of Battle Ground village, above Lafayette.

Individual wells.—Wells on the terraces of the Wabash near Battle Ground usually obtain no water within 50 feet of the surface, and in some instances are put down to a depth of 60 or 80 feet. Mr. J. M. Hicks's well, in the village of Battle Ground, is 79 feet, entirely through gravel, sand, or other alluvial deposits. Mr. J. P. Clute's well, in the same village, is 60 feet, striking blue till near the bottom. Wells east from Battle Ground, near the mouth of Moots Creek, are not infrequently 75 feet in depth, and are largely through sand and gravel.

On the uplands west from Battle Ground wells usually are obtained at about 20 or 30 feet, but are occasionally deeper. The following sections of wells in that region have been published by Mr. Gorby:[1]

John Livingston's well, 2 miles west of Battle Ground, penetrates—

	Feet.
1. Soil and yellow clay	30
2. Dry sand	20
3. Blue clay	30
4. Cemented gravel	2
5. Loose gravel	13
Total	95

[1] Fifteenth Ann. Rept. Indiana Geol. Survey, pp. 87-95.

James Bryant's well, 3 miles west of Battle Ground, penetrates—

	Feet.
1. Soil and yellow clay	4
2. Blue clay	50
3. Dry sand	20
4. Coarse gravel	2
Total	76

East of the Wabash, in the northern portion of the county, in the vicinity of Buck Creek village, wells are reported by Mr. Gorby to be occasionally 50 to 65 feet in depth. At John Stanfield's a well 65 feet penetrates sand nearly 50 feet before obtaining a coarse water stratum. At Moses Cole's, about 2 miles west of Buck Creek Station, a well penetrates 55 feet of gravel and sand, entering a blue till near the bottom. In Buck Creek village, W. W. C. Brown's well, 50 feet in depth, penetrates till 20 feet, beneath which is a fine yellow sand.

In eastern Tippecanoe County wells are usually obtained at 20 to 40 feet. Mr. Gorby reports an unusually large amount of yellow till in that region, it being frequently 23 to 30 feet in depth.

The gas-well boring at Dayton, in the eastern part of the county, penetrates about 300 feet of drift, of which a large part is thought to be sand.

At Lafayette an artesian well, in the valley of the Wabash, about 55 feet above low-water mark, or 560 feet above tide, penetrates 170 feet of drift and obtains a flow of water from the Lockport limestone at 230 feet. The section of this well published by Mr. Gorby shows variable beds of sand, gravel, and clay to a depth of 30 feet, where a dark-gray clay is entered which extends to the depth of 102 feet. Beneath this there is a series of sand, gravel, and clay beds about 30 feet, below which is a very bowldery bed, 40 feet in thickness, extending to the rock. An analysis of the water from this well appears elsewhere.[1]

The city water supply of Lafayette is obtained from a gravel bed under the Wabash River, about 40 feet below the bed of the stream. The water is found in such abundance at this horizon that the springs which arise from it furnish a considerable portion of the water flowing in the Wabash in dry seasons.

Private wells in Lafayette range in depth from 10 feet up to 60 feet, but are most numerous at 40 to 60 feet. As the city is located on a hillside, with variations of nearly 200 feet in elevation, the wells are obtained from several different horizons. Exposures of the drift are quite extensive in the southern part of the city. They uniformly show a large amount of sand and gravel beneath a comparatively thin sheet of till.

On the gravel terrace in west Lafayette, near Purdue University, which stands about 100 feet above the river, wells are often sunk to the level of the river bed through the sand and gravel of the terrace.

[1] Eighteenth Ann. Rept. U. S. Geol. Survey, Part IV, p. 498.

On the portion of the terrace below Lafayette, known as the Wea Plain, wells are frequently put down to a depth of 100 feet or more, thus reaching the level of the river. In the northeastern portion of the Wea Plain wells encounter a blue till before reaching the level of the river, but throughout much of the terrace the gravel extends below river level. A well on this terrace reported by Mr. Gorby has the following section:

	Feet.
1. Soil	3
2. Fine gravel	40
3. Sand and gravel	32
4. Gravel	40
Total	115

This well is located about 1½ miles south of the river in sec. 30, T. 23, R. 6 W. It is stated that at points nearer the river wells in some instances go to a depth of 125 or 130 feet before obtaining water. At points more remote from the river water is obtained at less depth.

In the southern part of the county wells are quite generally obtained at slight depth, seldom exceeding 30 feet and often but 12 to 20 feet. In this region there is very often a bed of water-bearing gravel or sand at the base of the yellow till, 10 to 15 feet from the surface, which affords sufficient water for wells. In some cases, however, wells are carried into the underlying blue till and obtain water at depths of 30 to 40 or 50 feet.

CARROLL COUNTY.

General statement.—Carroll County is situated in the north-central portion of the State and includes the part of Wabash Valley immediately above Tippecanoe County. Delphi is its county seat. Its area is 370 square miles. The greater part of the county lies on the east side of the Wabash River. On the west there is a narrow wedge of upland occupying the interval between the Wabash and Tippecanoe rivers. There is a continuous ascent from the east bluff of the Wabash southeastward beyond the limits of the county, an altitude of over 800 feet above tide being attained in its southeastern corner. The immediate bluffs of the Wabash are only 675 feet, while the stream is about 125 feet lower.

The surface of the county is either plane or gently undulating, if we except a few sharp drift knolls in the extreme northwest corner. The tributaries of the Wabash have all shallow channels. There is therefore no conspicuous topographic feature within the county except the Wabash Valley, which has a breadth of a mile or more and a depth of 125 to 150 feet. This valley is bordered by gravel terraces similar to those of Tippecanoe County, the highest of which stand fully 100 feet above the level of the river. Lower terraces occur at several heights.

The thickness of the drift varies greatly, there being quite extensive areas in the vicinity of Delphi, where rock is exposed up to a height

of nearly 50 feet above the river. At Monticello, near the northwest corner of the county, the rock floor is found at a level about 100 feet lower than the Wabash. Borings in neighboring portions of Howard and Clinton counties on the southeast show drift 200 to 250 feet or more in thickness, the rock floor being lower than at the outcrops along the Wabash River.

The drift of this county, so far as penetrated in wells, is generally a compact till. Exposures along the streams also are usually mainly till. The wells being shallow over the greater part of the county, the structure of the deeper portion of the drift is not known.

There are very strong springs in the vicinity of Delphi, from which the city water supply is obtained. Their location is about 3 miles northeast of the city, on the farm of George Snyder. The supply is piped to the city and distributed from the standpipe and also by direct pressure.[1]

Individual wells.—Wells are usually obtained at such shallow depths that records of but few of them were obtained. One of the deepest was found at Rockfield, in the northern part of the county, where till to a depth of 57 feet was penetrated and no rock encountered. The dug wells at Rockfield are only 15 to 25 feet in depth. Tubular wells are 50 feet or more.

Along the Wabash terraces, both above and below Delphi, wells are occasionally carried to a depth of 40 feet in gravel and sand; but in the vicinity of Delphi, where rock underlies the terrace at slight depth, they are sometimes found at the base of the gravel 10 to 20 feet. On the narrow strip of upland west of the Wabash records of two wells were obtained, each about 50 feet in depth, one of which was largely through till and the other largely through sand and gravel, though only 40 rods apart.

At Flora a gas-well boring penetrates 136 feet of drift thought to be largely till. There are several flowing wells at this village obtaining water at depths of 12 to 47 feet, the distance to the water-bearing stratum differing in the several wells. The wells are located on low ground along Bachelor's Run, and their head is only about 5 feet above the surface.

CLINTON COUNTY.

General statement.—Clinton County is situated in the north-central portion of the State, south of Carroll and east of Tippecanoe County, with Frankfort as its county seat. It has an area of 400 square miles. This county is an elevated plain, in which the slope is westward and northward from the southeast part. Its highest points are probably 950 feet above tide, while its lowest are about 700 feet. To the traveler, however, the county has the appearance of a nearly level plain, the rate of descent being gradual.

[1] Seventeenth Ann. Rept. Indiana Geol. Survey, p. 172.

The greater elevation of the southeastern portion of the county has been shown by numerous gas-well borings to be due, not to the height of rock surface, but to accumulations of drift, there being about 300 feet of drift in that part of the county.

The surface portion of the drift of this county is a compact till, but gas-well borings show that the deeper portion is largely sand and gravel.

Individual wells.—At Frankfort, the county seat, dug wells are usually obtained at 18 to 25 feet. Tubular wells find a large supply of water at 55 to 65 feet. The wells range in depth from 10 up to 90 feet. In the shallow wells sufficient clay is usually penetrated to insure freedom from surface contamination, though in some cases the water rises so near the surface as to be easily contaminated.

The city water supply of Frankfort is obtained from wells sunk to a depth of about 30 feet below a reservoir which is itself 28 feet in depth. The water fills this reservoir within 3 feet of the surface. Six wells, 8 inches in diameter, are estimated to furnish about 6,000,000 gallons a day. A gas-well boring in the northeast part of Frankfort has the following section:

	Feet.
1. Till	30
2. Quicksand	10 or 15
3. Hard clay and gravel, with flow of water near bottom	25 or 30
4. Gravel and sand, with thin clay beds	197
5. Blue pebbly clay	13
Total	278

A well in the western part of the city did not reach rock at 297 feet. For several miles south and east from Frankfort water is obtained at 15 to 30 feet, being mainly through till, with water-bearing gravel at bottom. North and west from the city the wells are often of greater depth.

At Scircleville a gas-well boring penetrated 296 feet of drift, of which the upper 150 feet is largely till, but the remainder is mainly sand and gravel. Near the east line of the county, about 3 miles east of Scircleville, a gas-well boring enters rock at 260 feet. The drift there is mainly a blue till.

At Kirklin, in the southeast part of the county, a gas-well boring has 252 feet of drift, of which the upper 40 feet is till, but the remainder has alternations of sand and gravel in thin beds, with somewhat thicker sheets of till. The wells in the vicinity of Kirklin obtain a strong supply of water at 40 feet. West from Kirklin wells are often obtained at 16 or 18 feet. Tubular wells are, however, 60 or 70 feet, mainly through till.

At Colfax the deepest wells are 60 or 70 feet, mainly through blue till. Shallower wells are, however, common in that region.

At Mulberry, in the western part of the county, at an elevation 754 feet above tide, a water well at the railway station, 220 feet in depth,

did not reach rock. It is mainly through till. Another well at a sawmill in the same village is 150 feet in depth, mainly blue till.

Near Gittingsville, in the northern part of the county, several flowing wells have been obtained at about 20 feet. They are along a valley in sec. 19, T. 23, R. 1 E. In section 30 of the same township a well at R. O. Young's, 71 feet in depth, penetrates till, with thin beds of gravel and sand.

In the vicinity of Sedalia, in the extreme northern portion of the county, wells are occasionally sunk to a depth of 80 feet through till, but are usually shallower. A well at J. H. Brown's, in sec. 24, T. 23, R. 1 W., 126 feet in depth, penetrates—

	Feet.
1. Till	68
2. Sand, with vegetal deposits and inflammable gas	16
3. Sand	42
4. Gravel, with water at bottom.	
Total	126

In the Fifteenth Report of the Indiana Survey attention is called to the occurrence of many bowlders in the blue till in Stony Prairie, 5 or 6 miles southwest from Frankfort, from the surface down to a depth of 50 feet. The western half of the county is liberally strewn with bowlders, but they seldom extend to such depth as to be troublesome in excavating wells.

HOWARD COUNTY.

General statement.—Howard County is situated in the north-central portion of the State, immediately south of Cass and Miami counties, with Kokomo as its county seat. Its area is 300 square miles. The entire surface of the county is plain or gently undulating, there being few, if any, knolls and ridges rising more than 20 feet above the general level. With the exception of a narrow belt along Wild Cat Creek, west from Kokomo, which is less than 800 feet above tide, and possibly a narrow strip on the north border, the county stands between the 800 and 900 feet contour.

The greater portion of the county has a moderate coating of drift, 75 feet or less. But the southwestern part has a larger amount, there being at Russiaville and neighboring points about 150 feet. Where the drift is of moderate depth it is composed mainly of till, but the deeper portions include much sand and gravel in their lower part. Wells not infrequently find abundance of water at 10 or 20 feet, in beds of gravel between the yellow and blue till, and they rarely penetrate to a greater depth than 40 feet.

Individual wells.—At Kokomo wells are usually obtained at 35 or 40 feet, either in gravel near the base of the drift or in the upper part of the underlying limestone. A few deep wells 100 to 150 feet have been sunk. The city waterworks are supplied from wells 100 feet in depth.

Several gas borings have been made in the vicinity of Kokomo. In some cases the wells have encountered 90 feet of drift, but there is usually a much smaller amount. Some of those in Wild Cat Creek bottom and on the plain south of the creek enter rock at 10 to 20 feet or less. As a rule, these wells are productive of gas. Those to the west of the city in some cases yield no gas, but, instead, a flow of water. In the Indianapolis Sentinel for July 18, 1895, it is stated that one of these wells had been turned to good account by a farmer for irrigation during a season of excessive drought. Where the water contains only a moderate amount of saline matter such wells might be made to return some small share at least of the expense incurred in drilling for the gas.

At the village of Greentown, 8 miles east of Kokomo, wells are usually obtained at 20 to 25 feet in gravel below till. A lower vein of water is obtained at 35 to 45 feet. Gas-well borings at this point show the drift to be about 85 feet in thickness.

At Fairfield, 6 miles southeast of Kokomo, wells are usually obtained at 20 or 30 feet, there being about 20 feet of surface till. The drift in the vicinity of Fairfield is shown by gas borings to range from 25 feet up to fully 75 feet in depth. The well near the railway station has 47 feet of drift, of which the upper 18 or 20 feet is till and the remainder gravel. A well 4 miles west of Fairfield was found to have 165 feet of drift.

A strong flow of fresh water was obtained from the limestone in a well half a mile north of Fairfield at a depth of 110 feet. It is estimated to discharge 5,000 barrels per day. The head is only 6 feet above the surface of the ground, and the well mouth at this point is 25 feet lower than at Fairfield railway station.

At Tampico, about 3 miles northeast of Fairfield, wells are usually obtained at 30 feet. The drift at that point is shown by a gas boring to be 103 feet in depth, of which the upper 25 feet is till; the remainder consists of alternations of sand and till. A well 3 miles northeast of Tampico, bored for gas, has 115 feet of drift. It is reported to have passed through a bed of soil containing leaves at a depth of 103 to 105 feet.

A gas well at Sylvanus Barrett's, in the southeast township of the county, has 98 feet of drift, of which only the upper 10 feet is till, the remainder being gravel, a part of which is cemented.

At Russiaville, in the southwest township of the county, the gas-well boring penetrates 153 feet of drift, as follows:

	Feet.
1. Yellow till	10 to 12
2. Sand with water	3 to 4
3. Blue till	40
4. Sand and gravel, with thin beds of till	95 to 100
Total	153

Water wells in that vicinity are obtained at shallow depths in the sand between till sheets.

TIPTON COUNTY.

General statement.—Tipton County is situated in north-central Indiana, immediately south of Howard County, with Tipton as its county seat. Its area is 260 square miles. The surface of this county, like that of Howard, is gently undulating, and there is a thicker deposit of drift in its western than in its eastern portion. The western portion is also correspondingly higher. In the southwestern part of the county the altitude exceeds 900 feet, while in the northeastern it is little more than 800 feet. The drift in the southwestern part is 250 to 300 feet in depth, while in the northeastern it is 75 to 100 feet. The surface portion of the drift is generally a compact till, but the deeper portion contains large amounts of sand and gravel.

Individual wells.—At Sharpsville, on the north border of the county, the gas-well borings pass through about 70 feet of drift, mainly till. Water wells are obtained at 20 or 25 feet or less, in thin beds of sand or gravel associated with the till.

At the village of Windfall, in the northeast part of the county, the drift at a gas boring is 72 feet. There are, however, thin beds of sand and gravel associated with the till, which afford water for the wells.

On the east border of the county, in the vicinity of Elwood, the drift ranges from 40 feet up to more than 100 feet in the several gas wells which have been sunk. It is mainly a blue till, but with the till there are beds of sand and gravel furnishing water at moderate depths.

In the vicinity of Hobbs Station, and southeastward to the southeast corner of the county, gas wells usually enter rock at about 70 or 80 feet, and the greater portion of the drift is till.

At Tipton, near the center of the county, the gas wells show 140 to 200 feet of drift, the greatest depth being found on the bank of Cicero Creek, in the east part of the city. The dug wells are often obtained at shallow depths, 12 to 20 feet, and it is thought they are liable to surface contamination, as the drift is of a porous, gravelly constitution. Better wells are found at 50 to 100 feet, after penetrating a sheet of till. Fresh water may be obtained from the limestone, also at several horizons down to about 400 feet, below which depth it is liable to become brackish. The city water supply is derived from near the top of the limestone.

At Kempton, in the western part of the county, water is usually obtained at about 35 feet, in the gravel between sheets of till. Several gas wells have been sunk in the vicinity of Kempton, which show the drift to be 240 to 300 feet in thickness. One of these borings, in the east part of the village, penetrates the following drift series:

	Feet.
1. Yellow till	10
2. Sand and till, each in beds a few feet thick	165
3. Gravel	65
4. Sand	17
Total	257

Another well in the village with 305 feet of drift penetrates—

	Feet.
1. Till, with thin sand beds	200
2. Sand and gravel	80
3. Hard brown till	25
Total	305

A gas well half a mile east of Kempton has 243 feet of drift, consisting mainly of till, but having thin beds of sand and gravel.

At the village of Atlanta a gas-well boring penetrates about 300 feet of drift. Several gas-well borings in the southwest part of the county also penetrate drift 250 to 300 feet.

The following drift section appears in a gas boring near the center of the county, 3 miles east of Tipton:

	Feet.
1. Till, yellow and blue	38
2. Gravel	5
3. Blue till	45
4. Gravel	15
Total	103

A gas well in sec. 10, T. 21, R. 5 E., penetrates 130 feet of drift, as follows:

	Feet.
1. Yellow till	10
2. Gravel	20
3. Blue till	80
4. Gravel	20
Total	130

GRANT COUNTY.

General statement.—Grant County is situated in the north-central part of the State, with Marion as its county seat, and has an area of 420 square miles. It is traversed nearly centrally from southeast to northwest by the Mississinewa River. Along the east border of this stream is the Mississinewa moraine, having a breadth of about 5 miles. Aside from this moraine the surface of the county is a gently undulating plain. The moraine itself has gentle swells and sags and is not strikingly in contrast with the plains. Its relief, however, being 50 feet or more, makes it a noticeable feature.

On the portion of the county west from the Mississinewa River the drift is usually thin, it being often but 20 feet or even less in depth. This district, however, appears to be traversed by deeply filled valleys in which the drift has a thickness of 150 to 160 feet or more. In the northeastern part of the county the drift deposits seldom fall below 100 feet, and probably average nearly 150 feet. Throughout the county the surface portion of the drift is generally a compact till. In places where the drift is thick the deeper portions are often made up largely of sand and gravel.

Individual wells.—At the city of Marion the waterworks are supplied from two classes of wells—first, drift wells 70 feet in depth; second, wells in limestone 240 feet in depth. From both classes of wells the water rises nearly to the surface. A well 8 inches in diameter is estimated to yield nearly 4,000 barrels per day. The drift at Marion ranges from about 30 feet in the north part of the city to 150 feet or more in the south part. The upper portion generally is till to a depth of 30 to 45 feet, the remainder largely sand and gravel.

At Jonesboro, about 6 miles above Marion, on the Mississinewa River, wells are obtained in gravel below till at depths of 10 to 45 feet. The gas-well boring in the village shows the drift to be 162 feet.

At Upland, in the eastern part of the county, wells are usually obtained at about 30 feet, in a bed of gravel between sheets of till. A few wells are sunk into the underlying rock and obtain water at about 150 feet. The waterworks supply is from these rock wells.

At Van Buren the gas well penetrates 92 feet of drift, largely till. Wells in the vicinity of that village are obtained at 20 or 30 feet.

A gas boring in the northwestern part of the county penetrates 182 feet of drift, which is reported to be mainly sand and gravel.

In the southwestern portion of the county, although the drift is thin, wells are usually obtained without entering the rock, there being generally a water-bearing gravel at the base of the drift. Gas-well borings in this part of the county show the drift to have the following thicknesses at the principal villages: At Switzer, 28 feet; at Swayzee, 22 feet; at Simms, 45 feet; at Point Isabel, 22 feet; at Fairmount, 5 to 35 feet, the thickness varying in different wells. At Fairmount water wells are often drilled into the rock to a depth of about 30 feet. The waterworks supply is from such wells.

BLACKFORD COUNTY.

General statement.—Blackford County is situated somewhat north of the middle of the eastern portion of the State, and is one of the smallest counties, having an area of 170 square miles. Its county seat is Hartford City. The Mississinewa moraine traverses the southern townships of the county from west to east, and occupies about 75 square miles. The remainder of the county is a plain. With the exception of a narrow belt in the northeastern part, along the Salamonie River, the drift of this county is about like that of northeastern Grant County—100 to 150 feet or more in thickness. In the northeast corner the thickness is but 20 or 30 feet, or even less. The drift is composed mainly of a compact till, though beds of sand and gravel are sufficiently numerous to supply water for most of the wells at moderate depths.

Individual wells.—At Montpelier, in the northeastern part of the county, wells are in some cases drilled into the limestone, though usually obtaining water at the base of the drift at depths of 15 to 30 feet.

At Mill Grove, in the eastern part of the county, a gas-well boring penetrates 143 feet of drift, mainly till. Water wells are usually obtained at moderate depths, seldom more than 40 feet. In a few instances, however, they reach a depth of fully 100 feet in that part of the county.

At Hartford City the several gas borings show the drift to range in depth from 80 feet up to 150 feet or more. It is composed of till, interrupted by occasional thin beds of sand. The waterworks supply is from wells drilled into the underlying limestone to a depth of about 250 feet. A well at one of the hotels in Hartford City enters rock at 112 feet. The upper 80 feet is a nearly solid bed of till, below which is 32 feet of sand and gravel. A well 1 mile northwest of Hartford City, in section 10, has 177 feet of drift, of which the upper 100 feet is till and the remainder largely sand. One well in the southeast part of Hartford City enters rock at about 80 feet after penetrating 60 feet of till and about 20 feet of sand.

JAY COUNTY.

General statement.—Jay County is situated on the eastern border of the State, somewhat north of the middle, with the county seat at Portland. Its area is 396 square miles. This county is traversed from west to east by two morainic belts, the Mississinewa and the Salamonie. The Mississinewa moraine is confined mainly to the southern tier of townships and has a breadth of about 5 miles. The Salamonie moraine is situated mainly in the northern tier of townships, but enters the northern portion of the middle tier near the State line. Its breadth is 3 to 5 miles. The remainder of the county has a nearly plane surface, sloping gently toward the north. With the exception of a few sharp knolls on the Salamonie moraine near Camden (Pennville post-office), in the northwest part of the county, the moraines have gentle swells and sags, which give them but little contrast with the gently undulating plains. They present, however, a nearly continuous ridge with relief of 30 to 50 feet or more above the bordering plains. The altitude of the southern portion of the county exceeds 1,000 feet. The northern border of the county falls below 900 feet.

The drift is composed mainly of a sheet of compact till, and its thickness probably averages about 100 feet. The rock is rarely struck at less than 50 feet, and at Geneva, near the north border of the county, a gas-well boring shows 350 feet of drift.

Individual wells.—Along the north border of the county, near the State line, rock is found at 10 to 20 feet, and wells are often sunk into it to slight depths. The thin drift, however, occupies but a few square miles. At Bryant, near the middle of the north line of the county, the drift was found to be 112 feet in thickness.

About 6 miles west of Bryant, in secs. 19 and 30, T. 24, R. 13 E., wells are difficult to obtain, the moraine at that point being composed

of till to a depth of 125 feet or more. One well has a depth of 125 feet, another 140 feet, and another 155 feet, none of which enter rock. About a mile west of these wells rock is struck at 130 feet in a well in section 13, Penn Township.

At Pennville, in southern Penn Township, on the Salamonie River, rock is struck at about 40 feet in several gas borings.

At Portland, the county seat, wells are often obtained at 14 to 30 feet in gravel, but more frequently they are drilled into limestone, which is entered at 30 to 60 feet in the vicinity of this town. A few wells have a depth of 150 feet. The waterworks supply is from wells drilled into the limestone. It is thought that the shallow wells are protected from contamination by a bed of clay which overlies the water-bearing gravel.

Immediately east of Portland wells are obtained in sand between yellow and blue tills at 12 to 20 feet; the blue till is struck at 15 to 30 feet, and extends to the underlying rock at 45 to 50 feet.

A well in section 18, Noble Township, 5 miles east of Portland, enters rock at 83 feet; one in section 17 enters rock at 160 feet, and one in section 7 enters rock at 57 feet. They are all situated near the south border of the Salamonie moraine and are mainly through till.

Near Bellefontaine, in the east part of the county, wells enter rock at 80 to 135 feet and are mainly through till.

At Como, 6 miles southwest from Portland, the drift is 80 feet, and at Red Key 73 feet, mainly till at both places.

At Dunkirk, in the southwestern part of the county, the best wells are obtained near the top of the limestone at depths of 65 to 100 feet. The waterworks are supplied from wells of this class. Shallower wells afford only a small amount of water.

Along the Mississinewa moraine, in the southern part of the county, farmers not infrequently have sunk wells to a depth of 50 to 75 feet or more before obtaining an adequate supply of water. This moraine appears to afford but little water at shallow depths.[1]

[1] The size of a single paper in this series being limited by law to 100 pages, the remainder of this paper—the portion relating to the southern part of the State—will be published as Water-Supply Paper No. 26 (in press).

INDEX.

	Page.
Adams County, description of wells in	51–52
Ainsworth, description of wells near	14
Albion, description of wells at	32, 34
Allen County, description of wells in	48–51
Ambia, description of wells near	64, 66
Amboy, description of wells at	58
Andrews, description of wells near	54–55
Angola, description of wells near	28–29
Atlanta, description of wells at	76
Atwood, description of wells at	36
Auburn, description of wells near	30
Avilla, description of wells near	33
Battle Ground, description of wells near	68–69
Bellefontaine, description of wells near	79
Benton County, description of wells in	61–66
Blackford County, description of wells in	77–78
Blair, description of well at	16
Bluffton, description of wells at	53
Boone Grove, description of wells at	18
Boswell, description of well near	64, 65
Bremen, description of wells near	38
Brimfield, description of wells near	34
Brooke, description of wells near	43
Bryant, description of wells near	78–79
Buck Creek, description of wells near	69
Bunker Hill, description of wells near	58
Burkett, description of wells near	37
Butler, description of wells near	30
Carroll County, description of wells in	70–71
Cass County, description of wells in	59
Chalmers, description of wells near	61
Chamberlin, T. C., cited	11
Chesterton, description of wells near	16
Churubusco, description of wells at	48
Claypool, description of wells near	37
Clinton County, description of wells in	71–73
Colfax, description of wells at	72
Collins, description of wells at	48
Columbia City, description of wells at	48
Crown Point, description of wells near	14
Dayton, description of well at	69
Decatur, description of wells at	51
Dekalb County, description of wells in	29–31
Delphi, description of wells near	71
Denver, description of well at	58
Dryer, C. R., cited	25, 26, 27, 28
Dunkirk, description of wells at	79
Earl Park, description of wells near	62
Elkhart, description of wells at	24
Elkhart County, description of wells in	23–25
Elwood, description of wells at	75
Erie ice lobe, description of	11
Etna Green, description of wells at	36
Fairfield, description of wells near	74
Fairmount, description of wells at	77
Flora, description of wells near	71
Fort Wayne, description of wells at	49
Fowler, description of wells near	63
Frankfort, description of wells near	72
Fulton County, description of wells in	46–47
Furnessville, description of well at	16
Galveston, description of wells at	59
Garrett, description of wells at	31
Geneva, description of wells at	52
Gibson, description of wells at	14
Gittingsville, description of wells near	73
Glacial conditions of Indiana	9–13
Goshen, description of wells at	24
Grant County, description of wells in	76–77
Greentown, description of wells at	74
Hageman, description of wells at	16
Hammond, description of wells at	14
Hartford City, description of wells near	78
Hawville, description of wells near	34
Hebron, description of wells at	18
Hessville, description of wells at	14
Hobart, description of wells near	14
Hobbs Station, description of wells at	75
Howard County, description of wells in	73–74
Hudson, description of wells near	29
Huntington, description of wells at	54
Huntington County, description of wells in	54–55
Illinoian drift sheet, description of	10
Inwood, description of wells at	38
Iowan drift sheet, description of	10
Jackson Center, description of wells near	18
Jasper County, description of wells in	44–45
Jay County, description of wells in	78–79
Jonesboro, description of wells at	77
Kempton, description of wells near	75–76
Kendallville, description of wells near	32–33
Kentland, description of wells near	41–42, 43
Kewanna, description of wells at	47
Kirklin, description of wells near	72
Knox, description of wells at	39–40
Kokomo, description of wells near	73–74
Kosciusko, description of wells at	36
Kosciusko County, description of wells in	35–37
Kouts Station, description of wells at	18
Lacrosse, description of wells near	21
Lafayette, description of wells near	69–70
Lafontaine, description of wells at	56
Lagrange, description of wells near	25–26
Lagrange County, description of wells in	25–27
Lagro, description of wells near	57

	Page.
Lake, description of wells at	14
Lake County, description of wells in	13-14
Lake Maxinkuckee, description of wells near	38-39
Laketon, description of wells at	56
Laporte County, description of wells in	18-21
Ligonier, description of wells at	35
Liverpool, description of wells at	14
Loess defined	10
Logansport, description of wells near	59
Marion, description of wells at	77
Marshall County, description of wells in	37-39
Maxinkuckee moraine, description of	11
Medaryville, description of wells at	46
Mentone, description of wells near	37
Metz, description of wells near	29
Miami County, description of wells in	57-58
Michigan City, description of wells near	19-20
Milford, description of wells at	36
Mill Grove, description of wells at	78
Miller Station, description of well near	14
Mishawaka, description of wells at	22
Monon, description of wells at	60
Monticello, description of wells at	60
Montpelier, description of wells at	77
Morocco, description of wells at	43
Mount Ayer, description of wells at	43
Mulberry, description of wells at	72-73
New Haven, description of wells near	50
New Lancaster, description of wells near	54
New Madison, description of wells near	57
New Paris, description of wells near	24-25
Newell, F. H., letter of transmittal by	7
Newton County, description of wells in	40-43
Noble County, description of wells in	31-35
Noblesville, description of wells near	34
North Galveston, description of wells near	38
North Judson, description of wells at	40
North Liberty, description of wells near	23
North Manchester, description of wells near	55-56
Oswego, description of wells near	36
Otterbein, description of wells near	64-65
Oxford, description of wells near	65-66
Pennville, description of wells at	79
Peru, description of wells near	58
Pierceton, description of wells near	36
Pleasant Mills, description of wells at	52
Plymouth, description of wells near	38
Porter County, description of wells in	15-18
Portland, description of wells near	79
Pulaski County, description of wells in	46
Remington, description of wells at	45
Rensselaer, description of wells near	45
Reynolds, description of wells near	60-61
Roanoke, description of wells near	54
Rochester, description of wells at	47
Rockfield, description of wells at	71
Rome City, description of wells near	34
Royal Center, description of wells at	59
Russiaville, description of wells near	74
Saginaw ice lobe, description of	11
St. John, description of wells near	14
St. Joseph, description of wells near	31
St. Joseph County, description of wells in	21-23
Scircleville, description of wells near	72
Sedalia, description of wells near	73
Sharpsville, description of wells at	75
Somerset, description of wells near	56
South Bend, description of wells near	22,23
South Milford, description of well near	27
Spencerville, description of wells near	31,50
Starke County, description of wells in	39-40
Steuben County, description of wells in	27-29
Sugar Grove, description of well at	63
Surrey, description of wells near	44
Talbot, description of well near	64,65
Tampico, description of wells at	74
Teegarden, description of wells near	38
Templeton, description of wells near	65,66
Till defined	12
Tippecanoe County, description of wells in	67-70
Tipton, description of wells at	75,76
Tipton County, description of wells in	75-76
Tolleston, description of wells at	14
Uniondale, description of wells near	53
Upland, description of wells at	77
Valentine, description of well near	28
Valparaiso, description of wells near	17-18
Valparaiso moraine, description of	11
Van Buren, description of wells at	77
Wabash, description of wells at	56
Wabash County, description of wells in	55-57
Walkerton, description of wells near	23
Walton, description of wells at	59
Warren, description of wells near	55
Warren County, description of wells in	66-67
Warsaw, description of wells near	36-37
Waterloo, description of well at	30
Wells County, description of wells in	52-53
West Lebanon, description of wells near	67
Wheeler, description of wells near	17
White County, description of wells in	60-61
Whiting, description of wells at	14
Whitley County, description of wells in	47-48
Williamsport, description of wells near	66-67
Winamac, description of wells at	46
Windfall, description of wells at	75
Wisconsin drift sheet, description of	10
Wolcottville, description of well near	27
Xenia, description of wells at	58

DEPARTMENT OF THE INTERIOR

WATER-SUPPLY

AND

IRRIGATION PAPERS

OF THE

UNITED STATES GEOLOGICAL SURVEY

No. 22

WASHINGTON
GOVERNMENT PRINTING OFFICE
1899

UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

SEWAGE IRRIGATION

PART II

BY

GEORGE W. RAFTER

WASHINGTON
GOVERNMENT PRINTING OFFICE
1899

CONTENTS.

	Page.
Letter of transmittal	9
Résumé of Water-Supply and Irrigation Paper No. 3	11
Climatic and geographic distribution of sewage-disposal works	11
Origin of sewage irrigation	13
Comparison of English and American sewage	13
Pollution of rivers	15
Sewage purification at manufacturing establishments	22
Massachusetts experiments on the purification of factory wastes	27
Paper-mill wastes	27
Wool-scouring wastes	27
Tannery wastes	28
Dyestuffs	29
Special experiments	30
Mechanical analyses of sands	31
Size of grain	31
Air and water capacities of sand	33
Limitation of size of dose	33
Purification obtained by intermittent filtration	34
Summary of Massachusetts experiments	34
Value of commercial fertilizers	35
Necessity of purification of sewage at towns on the Great Lakes	36
Effect of sewage on lake waters	37
Danger of winter typhoid	38
American sewage-disposal plants	41
Maine	41
Augusta, State Insane Asylum	41
New Hampshire	41
Concord, State Insane Asylum	41
Rockingham County Poor Farm	42
Massachusetts	42
Amherst	42
Brockton	42
Gardner	45
Greenfield	46
Lenox	46
Marlboro	46
Concord, Massachusetts Reformatory	48
Medfield	48
Mystic Valley	48
Natick	50
Norfolk County Jail	51
North Brookfield	51
Pegan Brook	52
Waltham, School for the Feeble-minded	52
Sherborn Prison	52

American sewage-disposal plants—Continued.
Massachusetts—Continued. Page.
South Framingham 52
Wellesley College 53
Westboro 53
Worcester 53
Worcester Insane Hospital 55
Plants projected in Massachusetts 56
Rhode Island 57
Central Falls 57
Pawtucket 58
Cranston, State institutions 59
Providence 59
Woonsocket 59
Connecticut 59
Bristol 59
Danbury 60
Lake Wauremaug 60
Litchfield 60
Manchester 60
Meriden 61
Waterbury 62
New York 62
Brewsters 62
Brooklyn, twenty-sixth ward 62
Chautauqua Assembly 63
Far Rockaway 64
New Rochelle 64
Hemlock Lake 64
Bath, Soldiers' and Sailors' Home 65
Batavia, State Institution for the Blind 65
Vassar College 65
Plants projected in New York 67
New Jersey 69
Atlantic City 69
East Orange 70
Essex Fells 70
Freehold 70
Lawrenceville School 70
Long Branch 70
Morris Plains Asylum 70
Plainfield 71
Princeton College 71
Summit 71
Westfield 72
Pennsylvania 72
Altoona 72
Norristown, State Hospital for the Insane 73
Reading 73
Wayne 74
West Virginia 74
Weston, State Insane Hospital 74
Texas 74
Paris 74
San Antonio 75
Temple 75

American sewage-disposal plants—Continued. Page.
Ohio ... 75
Alliance ... 75
Canton ... 75
Fostoria ... 76
Oberlin ... 76
Michigan ... 77
Wayne County poor farm ... 77
St. Johns ... 77
Illinois ... 77
Pullman ... 77
World's Fair ... 79
Wisconsin ... 79
Menominee Valley ... 79
Minnesota ... 79
Rochester Hospital for the Insane ... 79
Nebraska ... 80
Hastings ... 80
Colorado ... 80
Colorado Springs ... 80
Leadville ... 80
Trinidad ... 81
Montana ... 81
Helena ... 81
Utah ... 81
Salt Lake City ... 81
Arizona ... 82
Phœnix ... 82
California ... 82
Fresno ... 82
Los Angeles ... 82
Pasadena ... 84
Redding ... 85
San Luis Obispo ... 85
Santa Rosa ... 85
Stockton ... 85
Dominion of Canada ... 85
Berlin ... 85
Hamilton ... 88
London ... 88
London Hospital ... 88
Ontario Agricultural College ... 89
Waterloo ... 89
Publications relating to sewage utilization and disposal ... 89
Index ... 99

ILLUSTRATIONS.

		Page.
PLATE I.	Brockton, Massachusetts, filtration fields; *A*, Turnips and sweet corn; *B*, Pease, sweet corn, and beans	42
II.	South Framingham, Massachusetts, sewage farm; *A*, Sewage inlet to filter; *B*, Portion of cabbage field	52
III.	Works at Worcester, Massachusetts; *A*, General view of precipitation tanks; *B*, Another view of precipitation tanks	54
IV.	Filter areas as ridged for winter service at Pawtucket, Rhode Island.	58
V.	Sewage disposal at Plainfield, New Jersey; *A*, Main carrier as seen from screen tank (before erection of building); *B*, Distributing channel in bed No. 1	70
VI.	Sewage irrigation at Salt Lake City, Utah; *A*, Main ditch, outlet gate, and field of corn; *B*, Lateral ditch and method of irrigating corn.	80
VII.	*A*, Sewage irrigation at Phœnix, Arizona; *B*, Sidehill irrigation at Wayne, Pennsylvania	82
FIG. 1.	—Mechanical composition of materials available for sewage filtration	32
2.	—Air and water capacities of sewage filter materials	32
3.	—Limitation of size of single dose by air and water capacities	33
4.	—Plan of filter areas at Pawtucket, Rhode Island	58

LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF HYDROGRAPHY,
Washington, October 25, 1898.

SIR: I have the honor to transmit herewith a manuscript entitled Sewage Irrigation, Part II, prepared in October, 1897, by Mr. George W. Rafter, of Rochester, New York. This paper consists in part of material furnished for Water-Supply and Irrigation Paper No. 3, on Sewage Irrigation. In the printing of that paper it was found that the limit of 100 pages set by law would be exceeded in spite of considerable condensation in the form of statement. The original manuscript was therefore divided into two parts, the first, relating to the general subject and giving the practice abroad, having already appeared as Paper No. 3. The present manuscript, which has been considerably extended by Mr. Rafter, is devoted mainly to the discussion of data obtained in this country and in Canada, and of all the plants erected and operated, together with brief notes on the projected plants. There is included an appendix containing a list of publications relating to the subject.

Very respectfully,

F. H. NEWELL,
Hydrographer in Charge.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

SEWAGE IRRIGATION, PART II.

By GEORGE W. RAFTER.

RÉSUMÉ OF WATER-SUPPLY AND IRRIGATION PAPER NO. 3.

In a previous publication on sewage irrigation[1] we discussed the general principles governing the utilization of sewage in agriculture, as well as the relations of such utilization to the public health. It was shown, also, how the gradually increasing pollution of streams first led in England and other manufacturing countries, to a demand for sewage purification, and the probable value of sewage in agriculture was indicated.

In that paper the various methods of sewage disposal in common use were discussed, with special reference to the modern views about nitrification. Descriptions of methods of applying sewage were given with information as to the best crops for sewage farming, the proper quantity of sewage to be applied, limiting temperatures, cost of labor on sewage farms, sanitary condition of such farms, and a number of other important subjects which it is necessary that one should understand before embarking in sewage-utilization investments. Brief descriptions were also given of a number of the principal sewage farms in England, of the sewage farms of the city of Berlin, Germany, and of sewage utilization in France on the Plain of Gennevilliers.

In the present paper it is proposed to give additional data relating to stream pollution and sewage purification, together with a brief account, so far as it has been possible to obtain the information, of every sewage-disposal plant in the United States and the Dominion of Canada, whether now in use or abandoned, that has actually been built, or that has had plans prepared for its construction.

CLIMATIC AND GEOGRAPHIC DISTRIBUTION OF SEWAGE-DISPOSAL WORKS.

As regards rainfall, the United States divides naturally into three regions—the humid, subhumid, and arid. The humid region includes all of the country east of the Mississippi River, together with the States of Iowa, Missouri, Arkansas, and Louisiana west of that river.

[1] Water-Supply and Irrigation Paper No. 3, 1897, 100 pp., 4 pls.

It also includes portions of North Dakota, South Dakota, Nebraska, Kansas, Indian Territory, and Texas. The subhumid region may be taken to include the remainder of North Dakota, South Dakota, Nebraska, Kansas, Indian Territory, and Texas. The arid region embraces Arizona, California, Colorado, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming, although limited areas in several of these States and Territories may be classed as humid.

The great lack of water in the subhumid and arid regions would naturally indicate a relatively large development of sewage irrigation in those portions of the United States. As a matter of fact, however, other conditions than mere shortage of water have controlled—for instance, the degree of advancement of the towns themselves—and we accordingly find, on the whole, more sewage irrigation and general purification in the humid East than in the subhumid and arid West. The Western towns are, nevertheless, advancing rapidly, and we may expect changes in the figures in the near future.

The following paragraph gives the approximate statistics of sewage purification in the United States to-day:

In the humid region there are sewage-purification plants in operation, actually building, projected, or built and abandoned, distributed by States as follows: Maine, 1; New Hampshire, 2; Massachusetts, 32; Rhode Island, 5; Connecticut, 7; New York, 33; New Jersey, 11; Pennsylvania, 5; Maryland, 1; West Virginia, 1; Louisiana, 1; Texas, 3; Ohio, 11; Michigan, 2; Illinois, 2; Wisconsin, 2;[1] Minnesota, 1; a total of 120 for the humid region. In the subhumid there is 1 in Nebraska. In the arid region Arizona has 1; Colorado, 4; California, 8; Montana, 1; Utah, 1; Wyoming, 1, or a total of 16. There are also six plants in the humid portion of the Dominion of Canada.[2]

The foregoing figures indicate a total for the United States and Canada of 143. About 120 of these plants have been either built or projected in the last ten or twelve years. This total includes, so far as can be learned, all the purification plants of every kind, whether irrigation, intermittent filtration, or combined chemical-purification and filtration and irrigation plants, either actually in operation now or formally projected and in such a state of advancement as probably to be carried out in a few years.

The intermittent-filtration plants are properly included in a paper on sewage irrigation, because the filtration areas either now are used for raising crops or are likely in the end to be so used. As to the propriety of including the chemical-purification plants, it may be pointed out that this system of purification has been adopted in several towns before all the controlling conditions were taken into account. In one case an

[1] Aside from three plants for purifying manufacturing wastes, etc., there are only two sewage-disposal works in Wisconsin.

[2] The foregoing statistics of the distribution of sewage-disposal works were prepared in September, 1897. At the present date (February, 1899) there are a few additions.

eastern town has adopted chemical purification and operated the plant at large expense, in spite of the existence of ideal conditions for irrigation and filtration in the immediate vicinity. It is probable, therefore, that, as soon as the advantages of irrigation and filtration are more fully known, a number of the chemical-purification plants will be changed to either irrigation or filtration, or, without a complete change of plant, the effluents from chemical-purification works will be further treated by either irrigation or filtration. This proposition is especially true of a number of chemical plants in the State of New York, where the capitalized cost of chemical treatment will be considerably in excess of that of intermittent filtration, even though sand of the proper quality were transported some distance and high-grade filtration areas constructed. It is in this view of the case that the statistics of chemical-purification plants are herein included. There are also a number of cities and villages in the Eastern part of the United States where crude sewage is discharged into ponds, lakes, and running streams, which either now are or are likely in the future to be the source of public water supplies. In the end the sewage of all such will require purification. In many cases proper land areas can be had in the immediate vicinity; hence we find an additional reason why a complete exhibit of the whole subject should be made at this time. All town authorities need to understand that, with other conditions equal, the capitalized cost of the land-purification processes is ordinarily less than that of the chemical. Farmers in the vicinities of towns need also to understand this, as well as the benefits to themselves to be derived from the utilization of sewage in agriculture.

ORIGIN OF SEWAGE IRRIGATION.

The growth in England of great manufacturing industries and the consequent pollution of the streams of that country at the beginning of the present century forced the English cities to consider the necessity for sewage purification at an earlier date than elsewhere. Sewage irrigation as a branch of applied science may therefore be said to have originated in England. At the present time a more general use of sewage purification may be found in that country than elsewhere, although, as we have seen in Water-Supply and Irrigation Paper No. 3, the Germans and the French have now extensive sewage-purification plants of a high order of excellence. Nevertheless it is true that a large proportion of the data of sewage disposal, as it exists to-day, must necessarily be drawn from English practice.

COMPARISON OF ENGLISH AND AMERICAN SEWAGE.

First of all, it is necessary that we establish in some way a measure of the relation which average English sewage bears to American. The great difficulty in making comparisons is the fact that the English

chemists, following the lead of Dr. Frankland, have mostly used the combustion process in their sewage analyses, while in the United States the Wanklyn albuminoid-ammonia process has been almost exclusively used.

By way of explaining the terms used, it may be pointed out that free ammonia as determined by the Wanklyn process represents that portion of the nitrogenous matter present which has already, at the time of analysis, passed into a state of decay; whereas the albuminoid ammonia represents the nitrogenous matter which has not, at the time of analysis, undergone decay. These are the two main determinations of the Wanklyn process.

In the combustion process Dr. Frankland attained much greater refinement than is possible with the albuminoid-ammonia process of Wanklyn, and the only reason why the combustion process has not been universally adopted is because of the difficulty of working it. By its use we determine not only the different states of the nitrogen, but that portion of the organic matter present which is carbonaceous in its character, or, technically, the organic carbon. The organic nitrogen of the process is that portion of the nitrogenous matter due to living substances, and corresponds in a general way with the albuminoid ammonia of Wanklyn. The ammonia represents dead and usually animal matter, and is, in the opinion of Dr. Frankland, the chief index of recent sewage contamination.

There are four states of the nitrogen as found in contaminated water—ammonia, free ammonia, nitrite, and nitrate. The nitrates represent the final fixation of the ammonia by combination with a mineral base, and hence a state of innocuousness. By a comparison of these various states Dr. Frankland arrives at the previous sewage contamination, which is one of the most interesting determinations of his system.[1]

If we refer to the various reports of the Rivers Pollution Commission, the Royal Commission on Metropolitan Sewage Discharge, or the Royal Commission on Metropolitan Water Supply, or to the various reports of the English local government boards, we find the analyses usually given in terms of the combustion process, in which organic carbon, organic nitrogen, ammonia, and total combined nitrogen may be considered the chief controlling constituents. Referring to a table in the first report of the Rivers Pollution Commission, on pages 28 and 29, we find that in English water-closet towns the total solids in solution in the sewage amount, on an average, to 72.2 parts per 100,000; the organic carbon to 4.696 parts per 100,000; the organic nitrogen to 2.205 parts per 100,000; the ammonia to 6.703 parts per 100,000; the total combined nitrogen to 7.728 parts per 100,000; and the chlorine to 10.66 parts per 100,000. Of the suspended matters the minerals

[1] For a definition of these several elements of the combustion process in detail the reader is referred to Recent advances in water analyses, etc., by the author, in American Monthly Microscopical Journal, May, 1893, p. 127.

amounted to 24.18 parts per 100,000, and the organic to 20.50 parts per 100,000, giving a total of 44.69 parts. If we bear in mind that free ammonia, albuminoid ammonia, and organic nitrogen refer to the same things, and also that the organic nitrogen is usually about double the albuminoid, we may still make comparisons which are close enough for the ordinary purposes of agriculturists.

Comparing several series of analyses, both American and English, it becomes apparent that ordinary town sewage in England is usually considerably more concentrated than that of the American towns. It is very important to bear this in mind in applying English data to American conditions. The elaborate experiments conducted by the Massachusetts State board of health at Lawrence, which have been reported from year to year in the annual reports of that board from 1888 to the present time, indicate that there is a relation between the purifying capacity of different filtrating materials and the amount of impurity which can be removed from sewage of a given strength. This point is strongly brought out by the experiments. It follows, then, that if we prepare special areas for sewage purification in accordance with the indications of the Massachusetts experiments, we may expect to apply sowewhat larger volumes of average American dilute town sewage per unit of area than has usually been found expedient in English practice. If, therefore, we use English data without reference to the quality of the soil to which the sewage is to be applied, or of the sewage itself, we shall be likely to arrive at more or less erroneous conclusions.

As a summation of this part of our discussion, we may say that the chief object of sewage purification is to rid the sewage of a thousandth part, more or less, of the organic matter which it contains, and that all of the appliances for sewage purification and utilization may be considered as directed toward this one point.

POLLUTION OF RIVERS.

This division of the general subject has been discussed in Water-Supply and Irrigation Paper No. 3 under the general head of "Stream pollution." The following additional information is herewith presented by way of extending somewhat the discussion there given:[1]

As an exceedingly marked case of river pollution, we may refer to the report of the Passaic Valley Sewerage Commission, authorized by an act of the New Jersey legislature approved February 26, 1896. The report of the commission appointed under the terms of this act was issued in February, 1897, and therefore may be cited as one of the most recent extended studies on stream pollution to be had.

[1] For a more extended discussion of river-pollution questions the reader is referred to River pollution in the United States, by Charles C. Brown, a paper read before the Engineers' Club of St. Louis, June 18, 1890, and published in the Journal of the Association of Engineering Societies for October, 1890, Vol. X, No. 10, p. 475, and to Sewage Disposal in the United States, Chapter III. The two works give, with the present discussion, the bulk of the published information as to river pollution in the United States.

At its head waters, among the hills of Somerset County, New Jersey, the Passaic River is a pure, clear running stream. The same is true of its principal upper tributaries, the Rockaway and Pompton rivers; and while there is some manufacturing in the upper valleys, the river continues bright and inviting until it reaches Little Falls, at which place it receives the drainage from several residences and factories. After passing Paterson, 3 or 4 miles below Little Falls, its character completely changes, and from that point to Newark Bay, as stated by the Passaic commission, "its pollution is enormous, constant, and increasing yearly." About 436,000 persons now inhabit the district drained by the lower river, furnishing fully 70,000,000 gallons of sewage a day. So great is the extent of the pollution below Paterson that fish life, except a few hardy kinds, has entirely disappeared. The sewage-laden mud shores give out foul odors. Steam users report that the acids of the sewage-laden water have so affected their boilers as to make its use unadvisable. Formerly thousands frequented the river for pleasure purposes, but this is no longer a practice.[1]

In 1880 the population of the towns dischaging sewage into the lower Passaic River was 246,503, and in 1895 it was 436,423.

The ratio of increase in population of the lower Passaic district from 1880 to 1890 is placed at 43.2 per cent, and from 1890 to 1895 at 22.6 per cent. The river now receives the sewage of the cities of Paterson, Passaic, Orange, and Newark, and the towns of East Orange, Bloomfield, Montclair, Harrison, Kearny, East Newark, and part of Rutherford. All these places are growing rapidly, and sewerage facilities for a number of other places are an admitted necessity of the early future. The commission therefore considers it beyond question that the pollution of the lower Passaic is sure to increase enormously unless remedial measures be taken.

As a summation the commissioners state:

(1) That the daily discharge of 70,000,000 gallons of sewage into the Passaic River below the Great Falls of Paterson is beyond its power to assimilate.

(2) That through the stench the pollution has become a nuisance to residents along the banks, and has caused depreciation of property and injury to health.

(3) That fisheries have been destroyed.

(4) That the river has ceased to be desirable for pleasure purposes, boating, bathing, etc., no longer possessing the park value which so generous a stream should afford the large population on its banks.

(5) That the use of the river for manufacturing purposes is suffering on account of the pollution.

(6) In short, that the pollution of the lower Passaic River appears to the commissioners to be completely established as a public nuisance, as injurious to health, and as an increasing menace to property interests from the Great Falls at Paterson to below Newark.

[1] Abstract from report of Passaic Valley sewerage commission, pp. 10–11.

In discussing means of relief the commissioners state that the great progress in sanitary science of recent years has increased the demand for thorough methods of sewage disposal; hence it has been recognized in European countries, and throughout the thickly settled part of the United States, that methods of sewage disposal need a degree of care and thoroughness second only to the requirements of furnishing the same population with water and food. After reviewing the various methods of sewage purification the commissioners conclude that in the present case the conducting of the sewage to tidal waters is, on the whole, preferable. Their reason for this conclusion is, largely, that the available land areas in the Passaic Valley appear poorly adapted for irrigation and filtration processes. On this point the engineers to the commission, Messrs. A. Fteley and Charles E. A. Jacobson, state that the only lands within reach of sufficient area for irrigation works are the extensive meadows of the lower Passaic Valley, but unfortunately the character of the soil is so compact that, even with extensive and costly underdrainage, the amount of sewage which could be disposed of per unit of area would be so small as to require many thousands of acres; hence, Messrs. Fteley and Jacobson consider land disposal impracticable for the lower Passaic. They recommend the construction of an intercepting sewer at an estimated present cost of $6,500,000. The yearly cost of operation is placed at $125,000 in 1900 and $300,000 in 1930.

An extended series of chemical analyses made by Herbert B. Baldwin, chemist to the commission, is included in the report. In considering the effect of the sewage on the condition of the river, it is pointed out by Mr. Baldwin that the average discharge of sewage is a fairly constant quantity, but that the flow of the river is not. By way of illustrating this, we may point out that the flow of the Passaic River varies at Little Falls from a minimum of about 200 cubic feet to a maximum of about 20,000 cubic feet per second. The drainage area above Little Falls is 773 square miles. Whenever the river is either at or anywhere near its minimum flow, what may be termed the point of saturation is so far exceeded that the river inevitably becomes not only a nuisance, but a menace to health. On the one hand, the clearing of forests tends to decrease still further the minimum flow and to increase the length of the low-water period from year to year; on the other hand, the growth of towns and the extension of sewerage works tend to increase the pollution. Taking the two together, there is, therefore, a more rapid increase in actual stream pollution than is indicated by mere consideration of the percentages of increase of the quantity of sewage.

Moreover, the upper Passaic is the natural source of water supply for the north Jersey municipalities, and the probable taking of an appreciable part of the stream for such supplies will inevitably tend to aggravate existing conditions.

Chapter 83 of the Resolves of the Massachusetts Legislature of 1895 directed the State board of health to investigate the sanitary condi-

tion of the meadows on Neponset River, and submit the results of the examination, together with recommendations for the improvement of the sanitary condition of the meadows and the removal of the nuisance therefrom. The report of the board's engineers was made under date of October 1, 1896.

The Neponset Meadows, covering an area of 3,662 acres, of which little more than 600 acres appear to be in a condition adapted to agriculture, are subject to prolonged flooding nearly every year, and, with an increasing pollution of the stream, have become a serious public nuisance. The object of the report of the Massachusetts State board of health referred to is the abatement of this nuisance.

The Neponset River is connected with the Charles River by Mother Brook, which is legally entitled to receive one-third of the flow of Charles River. The drainage area of the Neponset River at its mouth, including one-third of the watershed of the Charles River above Mother Brook, is given as 180.3 square miles. The population of the several towns in the Neponset Basin above the lower end of the meadows was, in 1885, 15,097; in 1890, 17,361, and in 1895, 19,193. These towns are provided with public water supplies, but none of them have as yet a general system of sewerage.

The Neponset River may be divided into three portions: An upper portion, above the great meadows; a middle portion, including the meadows subject to overflow; and a lower portion, within the limits of the Boston metropolitan district.

The upper portion is about 10 miles in length, with a total fall of about 220 feet. Manufactories and mills are located throughout the valley, and the river is highly polluted by manufacturing wastes. The length of the middle portion is 11.25 miles. In much of this portion the river has very little fall and the flowing water is partially purified by dilution with water from purer tributaries and by sedimentation. The lower portion has considerable fall to tide water, and has high banks occupied by factories and dwelling houses. Practically all the water power of this section is made available by milldams. The minimum flow of the stream, as determined by the lowest level, reached in 1895, is about 54 cubic feet per second.

Chemical analyses of the water of the Neponset River were made by the Massachusetts State board of health in 1873, 1875, 1885, 1891, and 1895. A tabulation of the results shows a much more serious pollution in 1895 than in 1875. Thus, in 1875, at the Milton lower mills, free ammonia was 0.0112 part per 100,000; in 1891 it was 0.0274 part; and in 1895, 0.0526 part. In 1875 the albuminoid ammonia at Milton lower mills was 0.0171 part per 100,000; in 1891, 0.0329 part; and in 1895, 0.0342 part. Chlorine at Milton lower mills in 1875 was 0.46 part; in 1891, 1.18 parts, and in 1895, 1.47 parts.

The report states that, in order to improve the sanitary condition of the river and meadows, it will be necessary to prevent the further dis-

charge into the stream of domestic and manufacturing sewage, unless it has been previously purified sufficiently to prevent offense to sight or smell. A system of sewerage was provided for by chapter 406 of the Massachusetts acts of 1895, by means of which it will be possible in future to prevent the pollution of the river below the great meadows, after some provision is made whereby the diversion of sewage from the river into the sewers is made compulsory and the further discharge of manufacturing wastes is prevented.

The town of Hyde Park is located on the Neponset River, just below its junction with Mother Brook. The pollution in the region above at the present time is caused almost entirely by the discharge into the river of manufacturing wastes, generally from paper mills and tanneries. Investigations with reference to the purification of wastes of this sort were begun by the Massachusetts State board of health in the summer of 1895, and a résumé of the results will be found in the following pages. The published results indicate that it will be feasible to purify the manufacturing wastes satisfactorily at a cost sufficiently small to avoid crippling the manufacturing industries. A study of the question of the purification of the sewage of a number of towns naturally draining into the Neponset River in the upper valley shows that the necessary purification can be best accomplished by separate treatment upon land, as is done in many other towns in Massachusetts.

The removal from the river of the crude sewage of the manufacturing establishments, as well as that of the towns in the valley, will tend to improve the sanitary condition of the channel of the stream by preventing further deposition of organic matter upon the sides and bottom and in the numerous shallow bays and coves.

The report further states that, in order to improve the sanitary condition of the meadows, it will be necessary to lower the level of the water in the river sufficiently to permit the satisfactory drainage of the meadows and to prevent being flooded during the summer season. To accomplish this it is considered that the river should be deepened sufficiently to carry off the summer flows and still keep the water surface below the level of the meadows. Applying the run-off data of the Sudbury River watershed, for which a record covering twenty-one years is available, it appears that the river channel should be enlarged enough to enable it to carry at least 720 cubic feet per second, which would be sufficient for anything except a summer rainfall in excess of that of August, 1889, when the run-off of the Sudbury River for the month amounted to 2.55 inches on the watershed, the rainfall of the previous month of July being 8.94 inches and of the previous August 4.18 inches. The run off-of August, 1889, of 2.55 inches, was the largest for any summer month during the period 1875 to 1896, covered by the Sudbury measurements. In 1882 the August run-off of the Sudbury was only 0.10 inch. In 1883 the September run-off was 0.08 inch. In 1883 the total run off of the Sudbury for the summer months, June to

August, inclusive, was only 0.86 inch. In 1889 the total run-off of the summer months was 4.81 inches. According to the report of the engineer, an examination of the rainfall records of eastern Massachusetts for the period of thirteen years indicates that summer flows as heavy as in August, 1889, may be expected about once in ten to fourteen years; while for about two or three times in a century it may happen that the flow for some one of the summer months will be considerably in excess of that for August, 1889.

The plan for draining the Neponset Meadows includes, in effect, the cutting of a new channel across a number of sharp bends, thus considerably shortening the length and increasing the slope. It also includes removing the flashboards of the dam of the Mattapan Paper Mill, which is situated on the river about half a mile up the stream from the north line of the town of Hyde Park. The estimated cost of the river improvement, not including cost of land and water damages, is $127,115. It is also estimated that the increase in valuation of the 3,655 acres of meadow resulting from this improvement would amount to $101,330.

In concluding his report, Mr. Goodenough, the engineer of the State board of health, states that the gain in valuation of the meadows, produced by draining them, probably does not represent the full economic value of the improvement. By leaving the river and meadows in their present condition they become not only a source of annoyance, but a menace to the health of those living in the vicinity, and ultimately unfavorably affect the value of all real estate in the vicinity. Moreover, if a portion of the improved meadows should be utilized for market gardening, the value of such portion would be much greater than if used for hay and pasturage alone.

In order to show the great pollution to which streams in manufacturing districts are subject from the discharge of manufacturing wastes, we may further refer to the report on river pollution in Connecticut, by Prof. S. W. Williston, from which extracts have been made in Water-Supply and Irrigation Paper No. 3, first considering the case of Quinnipiac River. That stream has a drainage area of about 150 square miles, with a population thereon in 1890 of fully 40,000. Meriden, the chief city of the drainage area, had a population in 1880 of 15,540, and in 1890 of 21,652.

A measurement of the flow of the Quinnipiac River made August 3, 1888, gave about 7 cubic feet per second. A measurement on Monday, August 6, before the mills started, gave 5.5 cubic feet per second; at 10 a. m. the same day the flow was nearly 20 cubic feet per second. The rainfall is such that in ordinary years we may expect fairly uniform daily stream flows in the vicinity of Meriden.

In 1888 there were in Meriden 23 manufacturing establishments, with 5,708 employees, of whom 3,608 used water-closets.

In a year these manufactories produce the following amounts of polluting materials:

Polluting materials used by manufactories in Meriden, Connecticut.

Mineral acids	pounds..	891,700
Alkalies	do....	198,500
Mineral salts	do....	7,000
Inorganic and organic oils	gallons..	18,445
Asphaltum	pounds..	1,000
Soap	do....	7,000
Cotton waste	do....	2,000

The organic matter scoured from wool is stated at over 500 pounds daily. The total amount of manufacturing wastes turned into the stream is estimated at from 2½ to 3 tons daily, one-fourth of which is organic.

At Yalesville and Wallingford Professor Williston found 6 manufacturing establishments, with 1,060 employees, of whom 485 used water-closets. The polluting material used per year by the 6 establishments was reported as follows:

Polluting materials used by manufactories in Yalesville and Wallingford, Connecticut.

	Pounds.
Organic matter (about)	50,000
Acids	173,000
Alkalies	41,000
Minerals and mineral oils (about)	90,000
Total	354,000

The sewers of New Britain, Connecticut, drain partly into a tributary of the Quinnipiac River and partly into a tributary of the Connecticut River. The population of New Britain in 1880 was 11,800, and in 1890, 16,519. Professor Williston's canvass showed 12 establishments, with 3,075 employees, using water-closets which drained into Pipers Brook, a tributary of the Connecticut.

The following quantities of chemicals per year were discharged from these 12 establishments:

Polluting materials discharged from manufactories in New Britain, Connecticut.

	Pounds.
Metal salts	700,000
Free acids	100,000
Lime salts	35,000
Alkali salts	100,000
Soap	25,000
Fatty matter	100,000
Vegetable refuse	20,000
Total	1,080,000

Waterbury, the chief city on the Naugatuck River, in Connecticut, had, in 1880, a population of 17,806, and in 1890 a population of 28,646.

In 1887, 26 manufacturing establishments employed 7,571 persons, of whom 7,140 used water-closets.

The annual pollution from manufacturing wastes at Waterbury was placed as follows:

Polluting materials discharged from manufactories in Waterbury, Connecticut.

	Pounds.
Free acids	500,000
Metal salts	2,500,000
Alkaline salts	75,000
Soap	50,000
Fatty matters	200,000
Total	3,325,000

A large amount of interesting recent information in regard to river pollution in the United States is now available, but lack of space precludes further reference to it in this place.[1] The examples given will serve to illustrate the immense amount of polluting wastes that are daily being thrown into the rivers.

SEWAGE PURIFICATION AT MANUFACTURING ESTABLISHMENTS.

In England the pollution of streams from manufacturing wastes became very serious many years ago, and as the result of careful consideration of this special phase of stream pollution a number of sewage-disposal plants have been devised, especially with reference to purifying the sewage of each manufacturing establishment at the mill. A large amount of information in regard to such plants, with detailed plans, may be found in the fourth report of the Rivers Pollution Commission. As American examples, a number of cases cited by Mr. Clark in his report to the Massachusetts drainage commission, together with several recent ones, may be mentioned.

(1) The Wansuch Mills at Providence, Rhode Island, manufacture woolen and worsted goods extensively. The yearly amount of refuse contained in the waste water from this mill is stated to include about 64,000 pounds of dyestuffs, 1,000,000 pounds of alkali, 4,000 pounds of acid, 53,000 pounds of fuller's earth, and 400,000 pounds of grease. The waste water which contains this polluting material, and which originally flowed directly into West River, is stated as about 400,000 gallons a day. A dyeing and bleaching company located on the stream below the Wansuch Mills brought suit, alleging serious injury to its operations. After protracted litigation the supreme court granted a permanent injunction. In compliance with the injunction attempts were made to purify the waste water before permitting it to enter the river. For this purpose an acre and a half of land was prepared for filtration

[1] See the annual reports of the several State boards of health. The annual reports of the Provincial Board of Health of Ontario may also be referred to. As further illustrating the pollution of streams by mill wastes, reference may be made to the Eighty-third Annual Report of the Philadelphia Water Department (1885), pages 308, 309, where the detail of the daily wastes from an extensive carpet, blanket, and cloth mill may be found. The same data are also given on page 64 of Sewage Disposal in the United States. See also the report of the Second Rivers Pollution Commission.

by making furrows 4 feet apart on the surface. This process was fairly successful when first tried, but the land soon became clogged on the surface. The filtration process was then abandoned, although it seems clear from present information that with a larger area it could have been made successful. Purification by chemical precipitation was then adopted and has, so far as known, been continued since. For this purpose a set of six connected basins was excavated on the land previously used for filtration.

It is stated that about a barrel of lime is added to each 100,000 gallons of waste before pumping to the precipitation basins. This addition is made rudely, without either previously grinding or slacking the lime. The mill wastes flow continuously through the basins, with most of the deposition taking place in the first basin. The effluent from the last basin is said to appear to the eye about as foul as when it enters; this apparently indicates, in view of the satisfactory results gained elsewhere, defects in the practical management of the process. In the beginning sulphate of alumina was used as a precipitant, at a cost of about $6,000 per year for the whole amount treated, which, however, was considered too great an expense.

(2) At the Loraine mills, Saylesville, Rhode Island, a method of wool scouring is practiced by which the grease is recovered and most of the dirt is eliminated from the wash water before it is permitted to escape. The results at this mill indicate the recovery of about a ton of grease from each 18,000 pounds of wool washed. The cost of the plant for accomplishing this, not including buildings, was $2,500. The process is considered remunerative.

(3) Two mills in Millbury, Massachusetts, each scouring about 1,000 pounds of wool per day in the grease, retain the first scour in vats, which are cleaned periodically and their contents used as fertilizer. The process is considered remunerative at these mills.

(4) At the woolen mills of Robert Bleakie & Co., Hyde Park, Massachusetts, about 3,000 pounds of wool are scoured daily, the refuse from which, together with sewage and dyeing wastes, flows into a settling basin, whence the effluent passes into the stream. The settling basin consists of a cemented structure 80 feet long, 10 feet wide, and 3.5 feet deep; it is cleaned at intervals and the sludge is used for fertilizer, yielding for this purpose an estimated value of several hundred dollars a year.

(5) At Maxwell's tannery, Winchester, Massachusetts, a mechanical filter is used for straining bark and coarse lime from tannery wastes. The filter consists of a wooden box about 4 feet wide, 2 feet deep, and 60 feet long, divided into compartments filled with hay, through which the waste water filters. The effluent generally is clear, but of a deep mahogany color.

(6) The Nemasket mills at East Taunton, Massachusetts, applied to the State board of health in 1891 for advice with reference to disposing

of the sewage of the mill. The board advised that the waste water from the sinks be kept entirely separate from other wastes and conducted to a tight cesspool with an overflow therefrom into a filtering trench on the bank of the river. Also, that privies be provided in which all excrementaceous matters, both solid and liquid, be retained in water-tight vaults, to be cleaned from time to time, and the deposits buried in the ground not less than 100 feet from the Taunton River. The board expressed the opinion that by carrying out this plan the water supply of the city of Taunton, which is taken from Taunton River below the Nemasket mills, would not be contaminated by the mill wastes.

(7) The Menominee River Valley, in Wisconsin, adjacent to the city of Milwaukee, has been badly polluted for a number of years by wastes from large manufacturing establishments as well as from the public institutions of Milwaukee County. In 1893 the Wisconsin legislature instructed the State board of health to prepare plans and estimates for a sewerage system to serve this district. It also enacted further legislation, requiring all sewage to be filtered or otherwise purified to the satisfaction of the State board of health before being discharged into the stream. The act, however, failed to provide funds for preparing the plans, but most of the manufacturing establishments and public institutions have voluntarily introduced some method of treating their sewage. A recent letter from Dr. U. O. B. Wingate, secretary of the Wisconsin State board of health, indicates that the results obtained have been hardly satisfactory on account of adverse decisions of the Wisconsin courts[1] as to the powers of the State board, which have operated to prevent such supervision of sewage-disposal projects in Wisconsin as is now common in the more advanced States of the East and middle West.

The following are some of the particulars of the works actually constructed. At Schmidt's curled-hair works the solid matter of the liquid wastes is first screened out and the effluent then discharged upon porous soil, where it disappears. A similar system is in operation at McBride's sanitarium.

The National Soldiers' Home, with over 2,000 inmates and a daily flow of sewage of about 270,000 gallons, constructed an intermittent filtration system, the permanent success of which, however, is said to be doubtful because of the character of the soil of the filter areas.

At the shops of the Chicago and Northwestern Railway Company at Merrill Park a furnace has been provided for cremating the excrements.

The public institutions of Milwaukee County and the Miller Brewing Company have constructed combined chemical precipitation and mechanical filtration plants. The county institutions consist of a hospital, almshouse, two insane asylums, etc., having in all over 1,000 inmates. The flow of sewage is placed at from 250,000 to 400,000

[1] See also Sixteenth Ann. Rept. Wisconsin State board of health.

gallons a day. The sewage is first treated with lime and sulphate of alumina, and is subsequently filtered. The works are said to receive daily attention from a chemist, and thus far have furnished a clear effluent, free from odor, which does not undergo a secondary decomposition. However, according to information in Engineering News of January 13, 1895, it appears that this plant is not doing the work as thoroughly as it should because of overcrowding and too infrequent cleaning. The plant was originally designed to treat 480,000 gallons of sewage in twenty-four hours, which would certainly be a very large quantity from 1,000 inmates, even at insane asylums. If the present works actually have a capacity of 480,000 gallons in twenty-four hours, or, what is the same thing, a capacity for treating 480 gallons per capita per diem, they certainly ought to take care of the sewage from these institutions. The mechanical filter is said to be composed of limestone, Florida moss, and iron manganese. We understand that the process is patented, but probably does not represent the best practice in sewage purification at the present time, which may be the real reason for its failing to do the work properly.

The Miller Brewing Company, which produces perhaps 150,000 gallons of sewage a day, has a similar plant, the effluent from which is stated to be so unsatisfactory as to undergo secondary decomposition.

In a letter to Engineering News dated January 21, 1895, Dr. Wingate, the secretary of the Wisconsin State board of health, states that two of the plants which have been built in the Menominee Valley are satisfactory in their construction, but their management is unsatisfactory. He also states that the managers of the different institutions and manufacturing establishments have apparently the idea that constructing a plant is all that is necessary, that they have not furnished the necessary agents and help to keep the plants in proper condition, and that they have not managed them properly.[1]

Experience abroad has fully shown that purification works require attention; indeed, our own experience on this point is now so full, that it seems unnecessary for Americans to experiment further in that direction.

(8) In Ohio stream pollution from manufacturing wastes has assumed some importance, and the State board of health of that State has investigated a number of cases of such pollution, one of which may be referred to here. The Scioto Straw-Board Company, of Kenton, Ohio, discharges the wastes from its mill into the Scioto River. Complaints having been made to the State board of health that such discharge caused a public nuisance, an investigation was made in the summer of 1886. The following analyses of water from the Scioto River at Kenton indicate the extent of the pollution. In considering the significance of

[1] In a letter to the author, dated August 6, 1897, Dr. Wingate states that a drainage commission has been appointed to report to the next legislature, which will consider the whole question of Menominee Valley sewage disposal.

these analyses it should be understood that the Scioto River at Kenton is little more than a respectable brook. The average fall does not exceed 1 foot per mile for 30 miles. Analysis No. 1 is water from the Scioto River above the mill; No. 2, water from below the mill, and No. 3, from La Rue, a few miles below.

Analyses of water from Scioto River near Kenton.

[Grains per gallon.]

Number.	Lime.	Chlorine.	Mineral.	Organic and volatile.	Total solids.
1	8.98	0.25	20.30	9.68	29.98
2	63.32	6.49	84.09	130.63	214.72
3	13.33	1.45	31.26	18.19	49.45

So far as can be learned, the great increase in pollution of the stream did not affect the health of people living in the vicinity, although the fish in the stream were killed and there was at time of low water a serious effluvium nuisance. The remedy was the construction of a settling tank of from 3 to 5 acres. As to whether or not this has proved satisfactory there is no information at hand.[1]

(9) The waste waters at Tid's tannery, Stoneham, Massachusetts, were treated chemically during the years 1894 and 1895. The following results were obtained in the latter year. The total quantity of sewage pumped was 4,990,924 gallons, to which were applied as a precipitant 71,760 pounds of sulphate of alumina. The sludge amounted to 648,820 gallons, or 13 per cent of the sewage. It was disposed of to neighboring farmers, who carted it away for fertilizer. These works were first operated in 1893, by the city of Boston, in order to protect the Upper Mystic Lake.

(10) At Fitzgerald's tannery, also in Stoneham, Massachusetts, a series of precipitation tanks were constructed by the owner in 1895, arranged in such manner that the heavy particles of waste matter will settle as the sewage flows from one tank to another over separating partitions. In 1895, however, the quantity of sewage having increased to about 10,000 gallons daily in August, it was found necessary to use more chemical than the lime naturally present in the sewage. The owner thereupon constructed a vat for chemicals, and the Boston water department furnished and applied sulphate of alumina to the extent of 10,520 pounds from August, 1895, to January, 1896. The effluent from both these tanneries in Stoneham, while still highly colored from the tan bark, is stated to be on the whole fairly satisfactory. The use of a larger amount of chemicals would remove an additional amount of color, but at such increased cost as is considered not to be justified by the circumstances.

[1] The Ohio State board of health issued in 1898 a Preliminary report of an investigation of rivers, etc., of Ohio, which gives much information about the waters of that State.

MASSACHUSETTS EXPERIMENTS ON THE PURIFICATION OF FACTORY WASTES.

In the report of the Massachusetts State board of health for 1895 the results of investigations as to the disposal of waste liquors from various industrial processes are given. Among others may be found a discussion of the results obtained in the purification of the waste liquors from paper making, wool scouring, and tanning.

PAPER-MILL WASTES.

The experiments on purification of paper-mill wastes included the application for some time to a filter containing 60 inches in depth of sand of the effective size of 0.25 millimeter of the waste liquor resulting from cleansing rags in a paper mill by means of a boiling solution of caustic soda and lime. The rags cleaned are of all kinds and colors, and the resulting liquor, as stated, is very highly colored. It was applied to the filter at an average rate of 65,500 gallons per acre daily, with the result of great improvement in the appearance and analysis, although the effluent as it flows from the filter is still highly charged with organic matter in solution. The following is the analysis of the applied liquor: Free ammonia, 2.3 parts per 100,000; albuminoid ammonia, 4.1 parts; chlorine, 20 parts; oxygen consumed, 140 parts. The effluent shows: Free ammonia, 1.8 parts per 100,000; albuminoid ammonia, 2.29 parts; chlorine, 12.59 parts; nitrogen as nitrates, 0.105 part, and as nitrites, 0.0067 part; oxygen consumed, 84.36 parts. The nitrates and nitrites in the applied liquor are nil. It is clear, therefore, that some considerable nitrifying action has taken place in the filter, but it is the opinion of the board that the degree of alkalinity is so high as to prevent the full effect of nitrification.

WOOL-SCOURING WASTES.

The waste liquors of wool scouring were applied to a filter with the same depth of sand and effective size of grains as in the previous case, at the rate of 17,000 gallons per acre daily. The results, so far as obtained, show that while a considerable improvement of such a liquor can be obtained by intermittent filtration, still, owing to clogging of the upper layers of the sand, it appears desirable that a preliminary treatment, to remove a part of the dirt and fatty matters before filtration, should be applied. The average analyses of the waste liquor from wool washing and of the effluent were as follows: The applied liquor contained 17.3 parts of free ammonia per 100,000; albuminoid ammonia, 43.1 parts; chlorine, 60.13 parts; oxygen consumed, 232 parts. The effluent contained: Free ammonia, 27.8 parts per 100,000; albuminoid ammonia, 8.3 parts; chlorine, 47 parts; nitrates, 0.28 part, and no nitrites; oxygen consumed, 90 parts. The applied liquor was entirely free of both nitrates and nitrites. A refiltration of the effluent

from the preceding experiment on waste liquor from wool scouring was made through two filters, one containing 60 inches in depth of sand of the same effective size of grain as before and the other containing 60 inches in depth of coke breeze. The effluent was applied to the two filters for three months, at the rate of 50,000 gallons per acre daily. The liquor passed through both the sand filter and the coke breeze very little changed, thus showing not only the stable character of the organic matters present, but that the high degree of alkalinity was probably prejudicial to nitrification.

An experiment was also made as to the treatment of the waste liquor from wool scouring by the preliminary precipitation of the fat and dirt by means of calcium chloride, followed by intermittent filtration. This treatment gives an almost complete clarification of the liquor, but it passed through a filter 5 feet in depth, with effective size of sand grain of 0.25 millimeter, with very little change.

TANNERY WASTES.

In order to test the efficiency of intermittent filtration as applied to tannery wastes, an experimental filter has been set up at Norwood, Massachusetts. On account of the conditions imposed by the location, the filter has only 2 feet of sand, the effective size of the sand grain being 0.14 millimeter. The sewage applied is a mixture of the waste liquors from all the processes carried on in the tannery; and it was applied to this shallow filter at an average rate of 55,000 gallons per acre daily. The results obtained were as follows: The applied sewage contained 3.1 parts of free ammonia per 100,000; albuminoid ammonia, 3.16 parts; chlorine, 312 parts; nitrates, 0.16 part; nitrites, 0.0015 part; oxygen consumed, 55 parts. The effluent contained: Free ammonia, 2.34 parts per 100,000; albuminoid ammonia, 0.6 part; chlorine, 290 parts; nitrates, 1.05 parts; nitrites, 0.01 part; oxygen consumed, 7.5 parts.

This sewage is said to be very strong and offensive, containing decaying animal tissues and the bran added to cause fermentation. It is also colored by the dyes used in finishing the hides, which, after a few weeks, the filter failed to remove completely. The applied sewage did not contain any amount of the spent tan liquor. The antiseptic qualities of the tannic acid would, without doubt, be very prejudicial to nitrification.

In cleaning hides a large amount of lime is used, in consequence of which in large tanneries there is an almost continuous stream of lime water flowing into and mixing with the other waste liquors. By properly arranged settling tanks and the regulation of this lime water, it is the opinion of the Massachusetts board that a large percentage of the sludge could be precipitated out. Experiments show that probably 60 per cent of the organic matter can be removed in this way, although even then the resulting supernatant sewage would still remain very rich in organic matter in solution.

The supernatant sewage from such treatment was applied to a small filter at the average rate of 120,000 gallons a day. After several months' operation this filter is stated to be in a state of active nitrification, giving a clear and nearly odorless effluent. It is the opinion of the Massachusetts board that by treatment of tannery sewage on this line it may be efficiently purified by filtration.

DYESTUFFS.

Among the many experiments carried out at Lawrence, perhaps as interesting as any, are those relating to the filtration of sewage containing dyestuffs. This division of the sewage question is specially interesting because of the large number of manufacturing establishments at various places, the refuse from which usually passes without treatment into streams. In England this phase of sewage purification became of considerable importance early in the present century, because, generally speaking, the streams of England are small, and even sixty years ago a number of them had become badly polluted by the waste dyes from woolen, cotton, and other fabric manufacturing establishments. As illustrating the conditions twenty-five years ago, the Second Rivers Pollution Commission gives in its third report a reproduction of a memorandum written with the water of the river Calder at a point where the Wakefield sewer enters that stream. This memorandum reads as follows: "Dedicated without permission to the local board of health, Wakefield. This memorandum written with water taken from the point of junction this day, between the river Calder and the town sewer. Could the odor only accompany this sheet it would add much to the interest of this memorandum."

The condition of the river Calder has been improved in recent years by the construction of a number of sewage purification works along its banks, although when seen by us in October, 1894, it was still far from being a limpid stream.

Without going into the detail of the Massachusetts experiments on the filtration of various dyes used in fabric manufacturing, we may simply state that indigo extract, logwood extract, alizarin base, archil B, rose azurine, benzo-azurine, methyline blue, orange 2 R, magenta, malachite green, and scarlet 2 R, when applied at varying rates—from 335,000 gallons per acre of archil B to 1,280,000 gallons per acre of methyline blue—gave an effluent absolutely free from color. Scarlet 2 R applied at the rate of 1,076,000 per acre gave an effluent as highly colored as the applied sewage, but when applied at the rate of 720,000 gallons per acre the effluent was without color. Patent blue, when applied at the rate of 56,000 gallons per acre, gave a slight color; it also gave a slight color when applied at the rate of 160,000 gallons per acre, but when applied at the rate of from 335,000 gallons per acre to 960,000 gallons, it gave, in each case, a strongly colored effluent.

Indigo extract, logwood extract, alizarin base, and archil B are dilute

colors. The others are coal-tar colors in concentrated form. In most of the experiments the removal of the color, as already stated, was complete, as tested by viewing the effluents in tubes of from 200 to 600 millimeters depth.

Considering the large quantities of dyestuffs applied in these experiments, the conclusion may be drawn that dyes as likely to exist in ordinary city sewage are easily amenable to filtration treatment.

SPECIAL EXPERIMENTS.

In the course of the experiments at Lawrence a number were made as to the effect of antiseptics, as well as other substances, upon nitrification. Some of the more important of these experiments may be briefly referred to.

(1) For several weeks a considerable quantity of egg albumen, a substance nearly insoluble in water, was applied in one of the experimental tanks, the object being to determine to what extent it would be rendered soluble and converted into free ammonia. The indications of the first experiment were that about 61 per cent of the total nitrogen contained in the albumen applied was rendered soluble and converted into nitrates. A repetition indicated that possibly 90 per cent of the total nitrogen of the albumen was converted into nitrates.

(2) To one of the experimental tanks, which at the time of the first application was giving a perfectly nitrified effluent, a solution of ammonium chloride, in water containing 1 part of ammonia per 100,000, was applied in place of the sewage. Enough sodium carbonate was mixed with the ammonium chloride solution to combine with the chlorine of the ammonium chloride, and also with the nitric acid equivalent to the ammonia. Nitrification was complete from the first, the effluent being not only free from ammonia, but containing nearly all the nitrogen applied, as nitrates. The strength of the solution was gradually increased until it contained 34 parts per 100,000 of ammonia, after which complete nitrification was not at once obtained, but finally a nearly complete nitrification resulted.

(3) Experiments as to the the effect of an excess and deficiency of alkali were also made, showing that with alkali in excess nitrification was not in the least interfered with, but with a deficiency the process apparently stopped with the production of an enormous quantity of nitrites.

(4) Experiments as to the effect of acid upon nitrification were made, which showed that sewage containing a large percentage of sulphuric acid may have a major part of its nitrogenous constituents removed for a considerable time. If we are dealing with a sewage which contains moderate quantities of sulphuric acid occasionally, we may expect to purify it by intermittent filtration without any ill effects; but if the sewage contains sulphuric acid regularly, the acid should be neutralized by the addition of lime or some other alkali.

(5) Experiments as to the effect of common salt showed that when common salt was present in such quantity that the chlorine amounted to 1,200 parts per 100,000 the nitrification was quickly checked and the common-salt solution passed through the filter almost unchanged. If, however, common salt be added gradually, so that the filter may have the opportunity to adapt itself to the work required of it, the result was found to be very different. In an experiment of this character it was ascertained that with gradual increase of the common-salt solution nitrification continued. The practical result arrived at was that sewage containing a considerable quantity of common salt as one of its regular constituents may be purified by intermittent filtration without difficulty.

(6) Experiments as to the effect of sugar upon nitrification showed that if a considerable quantity of sugar is applied to intermittent filtration it will cause a decrease of nitrification. If, however, the filter can be gradually adapted to the special work of nitrifying sugar, the nitrification will finally become nearly as complete as when sugar is absent.

MECHANICAL ANALYSES OF SANDS.

The selection of the filtering materials is a very important point in constructing a filter. The Massachusetts State board of health has developed a method of sand analysis by which different sands may be compared and from their relative coarseness their efficiency as a filter material be foretold.

SIZE OF GRAIN.

As described in the twenty-third annual report of the board, the sand is first sifted through a series of sieves, each about twice as fine as the one next coarser. The sand passing the finest sieve is divided into several portions by beaker elutriation. Each portion is weighed, and the range and size of particles is determined either by micrometer measurement of the smaller particles or by computation of the diameters of larger particles by their weight. The diameters of all particles are taken as nearly as possible at the diameter of a square of equal volume. In each case the diameters are expressed in millimeters. As illustrating the results of such mechanical analyses in their application to filter material, we may quote the following as the percentage statement of the fine material used in experimental filter No. 5. In this filter the material with mean diameter less than 12.6 millimeters amounted to 99 per cent of the whole; material with less diameter than 6.2 millimeters to 96 per cent of the whole; mean diameter less than 2.2 millimeters, 92 per cent; mean diameter less than 0.98 millimeter, 89 per cent; mean diameter less than 0.46 millimeter, 80 per cent; diameter less than 0.24 millimeter, 67 per cent; diameter less than 0.12 millimeter, 51 per cent; diameter less than 0.06 millimeter, 33 per cent; diameter less than 0.03 millimeter, 16 per cent; diameter less than 0.01 millimeter, which would represent the organic matter, 6 per cent.

We have an example of the mechanical analysis of a coarse sand in the case of sand from filter No. 1. In this filter the material with mean diameter less than 12.6 millimeters amounted to 100 per cent of the whole; material with diameter less than 6.2 millimeters, to 97 per cent of the whole; mean diameter less than 2.2 millimeters, 85 per cent; mean diameter less than 0.98 millimeter, 53 per cent; mean diameter less than 0.46 millimeter, 7 per cent; mean diameter less than 0.24 millimeter, 1.5 per cent; mean diameter less than 0.12 millimeter, 0 per cent.

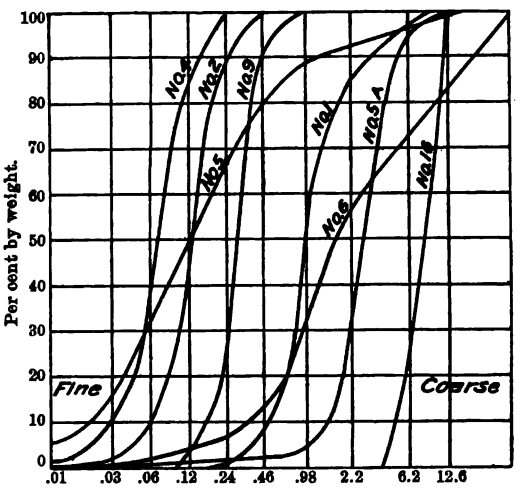


FIG. 1.—Mechanical composition of materials available for sewage filtration.

In the same way the results of the mechanical analysis of other sands used in the Lawrence experiments are expressed in the reports.

In order to compare the results of the mechanical analyses of the several sands experimented with as well as their relative values for filtration, we include the accompanying diagram, fig. 1, derived from the Massachusetts reports. The lines representing the diameters are spaced according to the logarithms of the diameters of the particles, as in this way materials of corresponding uniformity in range of size of particles give equally steep curves, regardless of the absolute size of the particles. The materials indicated by fig. 1 are stated by Mr. Hazen to include the whole range of the sands available for sewage purification.

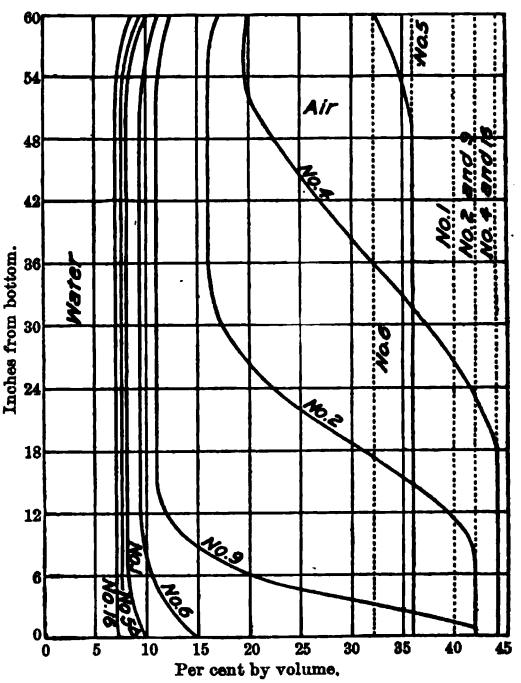


FIG. 2.—Air and water capacities of sewage filter materials. Full lines represent water capacity and dotted lines air capacity.

AIR AND WATER CAPACITIES OF SAND.

In order to estimate the filtering capacity of any given material, it is important to understand the air and water capacity of the filtering material when drained, the term "water capacity" being taken to designate the amount of water retained in the interstices after thorough draining. It is clear from what has preceded that the efficiency of the filtering process must depend largely upon these two elements. In fig. 2, also derived from the Massachusetts reports, the air and water capacities of the same materials illustrated by fig. 1 are shown, though in studying this diagram it should be borne in mind that the curves for air space and water capacity can be taken only as general averages, because the tenacity of the material can be varied greatly in packing. It is obvious that the amount of water will depend not only upon the closeness of the packing but also upon its uniformity, the tendency always being toward an increase of the water capacity. It will also depend at any given time upon the amount of organic matter stored from the material filtered. The water capacity will also depend largely upon the size of the particles, the finer sands holding much water, especially at the bottom, while with coarse sands the amount held will be nearly constant from top to bottom.[1]

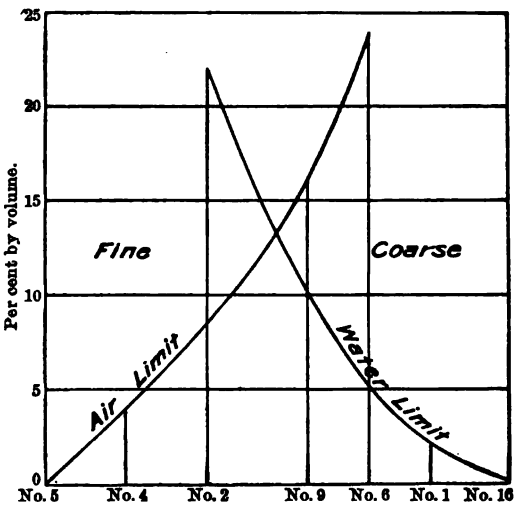


FIG. 3.—Limitation of size of single dose by air and water capacities.

LIMITATION OF SIZE OF DOSE.

The diagram, fig. 3, also taken from the Massachusetts reports, will illustrate the range of capacity with different materials in this particular. This figure illustrates the limit of size of a single dose with reference to air and water capacities. The various materials are indicated by vertical lines, while the per cent of total volume is indicated by horizontal lines, the lower portion of the two curves showing the maximum dose for any given material which can be applied at one time with good results. If the dose is greater than that indicated in the curve of water limit, it is probable that some will pass the filter before

[1] Reference to the twenty-third annual report of the Massachusetts board will furnish a discussion of these important practical questions in full detail.

complete purification. If the air limit is exceeded, the oxygen in the filter is liable to be exhausted before the oxidation is complete.

In the line of these studies the Massachusetts reports give a table showing the doses proved to be adapted to the various materials under the most favorable conditions of management. For material No. 16 of the preceding diagrams, as actually applied in practice at the experiment station, the dose was 2,800 gallons per acre, applied 500 times a week, this amount giving a daily average of 200,000 gallons per acre. For material No. 1 the size of dose is 40,000 gallons, applied 18 times a week, giving an average daily amount of 103,000 gallons per acre. For material No. 6 the size of dose is 70,000 gallons per acre, applied 6 times a week, giving a daily average of 60,000 gallons per acre. For material No. 9 the size of dose is 120,000 gallons an acre, applied 6 times a week, giving a daily average of 103,000 gallons per acre. For No. 2 the dose is 140,000 gallons an acre, 3 times a week, giving a daily average of 60,000 gallons per acre. For No. 4 the dose is 80,000 gallons, 3 times per week, giving a daily average of 34,000 gallons per acre. The depth of the material to which these applications were made was in every case, with the exception of No. 6, 5 feet; for No. 6 the depth was 4 feet.

As stated in the report, it must be borne in mind that the above figures are applicable only to clean materials under favorable conditions, and that in order to apply large doses permanently with good results the surface material must be occasionally renewed, as already discussed.

PURIFICATION OBTAINED BY INTERMITTENT FILTRATION.

As to the degree of purification obtained by intermittent filtration, the Massachusetts experiments show that very high degrees are reached easily. By way of illustrating the matter we may simply cite that city sewage has been purified to the extent of removing from 95 to 99.5 per cent of the polluting material. Sewage containing from 500,000 to 1,000,000 bacteria per cubic centimeter has been experimentally so far purified of bacteria that the effluents have frequently contained as few as from 25 to 100 bacteria per cubic centimeter. In order to appreciate this degree of bacterial purification we may consider that well waters in common use frequently contain from 2,000 to 3,000 bacteria per cubic centimeter. As regards chemical and biological considerations there is therefore no reason why such sewage effluents are not fit to drink.

SUMMARY OF MASSACHUSETTS EXPERIMENTS.

The body of information in regard to sewage purification by intermittent filtration which is presented in the several reports of the Massachusetts State board of health has become so extensive that one must be an expert to keep in mind the many interesting and valuable results brought out. As assisting the general reader, who may not care to travel through the several thousand pages of matter given in these reports, reference may be made to the very excellent summary of

the results obtained from intermittent filtration during seven years' experimentation, which appears on page 497 of the report of 1894, where may be found brief statements of yearly averages of the various kinds of filters experimented upon, as well as an outline of the most important features in the operation of each filter.

In concluding, it is pointed out that—

(1) The qualitative efficiency of the filters is lower in winter than in summer chiefly because of the inactivity of the nitrifying organisms when exposed to low temperature. The indications at present are that it is not advisable to allow exposed filters to rest in winter, even for limited periods.

(2) Qualitative deterioration is a serious matter in winter, because nitrification can not be promptly reestablished as in summer.

(3) It has been learned, however, that when nitrification is active at the beginning of winter it may by proper treatment be preserved during the cold season. To this end frost should not be allowed to penetrate into the interstices of the filters.

(4) The warmer the sewage, within limits, the better the results. Where high degrees of purification are imperative in winter the sewage may be heated to a temperature of 100° F. We may conclude, then, that the arrangement of the filter bed should be with reference to preserving, so far as possible, the heat actually present in the sewage as it arrives in the filter. For this purpose the trenching of the filter area is especially efficient, because it concentrates the heat, thus aiding in preserving the biological process in a state of efficiency.[1]

(5) In any case sewage should be so applied as to penetrate all portions of the filter, as otherwise the passage through will be rapid and irregular, thus tending to a low degree of purification.

(6) The composition of sewage, particularly as regards the kind of sewage, is a much more marked factor in winter than in summer. This is true even in the case of experimental filters, where special lines of treatment to keep the filters in operation are feasible.

VALUE OF COMMERCIAL FERTILIZERS.

In order to indicate the theoretical value of the nitrogen, phosphates, and potash of crude sewage, the following statement of trade values of fertilizing ingredients in raw materials and chemicals of commercial fertilizers, as used by the agricultural experiment stations of the country, is included. The valuations obtained by the use of these figures agree fairly well with the average retail price of standard materials. The price per pound, in cents, is as follows:

Value of chemical ingredients in commercial fertilizers.

	Cents.
Nitrogen in ammonia salts	17
Nitrogen in nitrates	15.5
Organic nitrogen in dry and fine-ground potash, meat, and blood, and in high-grade mixed fertilizers	17.5

[1] For an estimate in detail of the cost of heating sewage see Rafter and Baker's Sewage Disposal in the United States, p. 336.

	Cents.
Organic nitrogen in cotton-seed meal and castor pomace	16.5
Organic nitrogen in fine-ground bone and tankage	15
Organic nitrogen in fine-ground medium bone and tankage	12
Organic nitrogen in medium bone and tankage	9
Organic nitrogen in coarse bone and tankage	7
Organic nitrogen in hair, horn shavings, and coarse potash scraps	7
Phosphoric acid, soluble in water	6.5
Phosphoric acid, soluble in ammonium citrate	6
Phosphoric acid in fine bone and tankage	6
Phosphoric acid in fine medium bone and tankage	5
Phosphoric acid in medium bone and tankage	4
Phosphoric acid in coarse bone and tankage	3
Phosphoric acid in fine-ground fish, cotton-seed meal, castor pomace, and wood ashes	5
Phosphoric acid in fine-ground rock phosphate	2
Potash as high-grade sulphate in forms free from muriates (chlorides), in ashes, etc	5.5
Potash in kainit	4.5
Potash in muriate	4.5
Organic nitrogen in mixed fertilizers	17.5
Insoluble phosphoric acid in mixed fertilizers	2

Value of fertilizing ingredients in foods.

	Cents.
Organic nitrogen	17.5
Phosphoric acid	5
Potash	5.5

NECESSITY OF PURIFICATION OF SEWAGE AT TOWNS ON THE GREAT LAKES.[1]

According to statistics of the Eleventh Census, the basin of the Great Lakes, especially the area contiguous to Lakes Ontario, Erie, and Michigan, is, next to the Atlantic seaboard, the most densely populated area of the United States. Bordering on Lakes Ontario, Erie, and Michigan are great and rapidly growing cities from which all of the sewage now passes into these lakes. The surrounding regions are usually not greatly elevated above the lakes, and hence do not afford any opportunity for obtaining upland waters for municipal supplies. The water supplies of towns on the Great Lakes are not only now almost universally taken from these bodies of water, but must necessarily continue to be so taken in the future. At present the sewage of the Great Lake cities is discharged without treatment into the same bodies of water from which the public water supplies are taken. An exception is the city of Rochester, which wisely brings its water supply by gravity from Hemlock, an inland lake about 30 miles distant; but Buffalo, Erie, Cleveland, Detroit, Chicago, Milwaukee, and many other towns take their water supplies in the manner stated. Without going into details for all the Great Lakes, we will state that Lake Michigan alone receives at the present time the sewage of municipalities and small towns aggregating over 2,000,000 people, and this population is rapidly

[1] This chapter is presented to illustrate the vast importance which sewage-purification studies are rapidly assuming in the United States.

increasing, having about doubled in ten years. A similar increase in population has taken place in the cities and towns tributary to the lower Great Lakes. Thus, Detroit had a population in 1880 of 116,340, and in 1890, 205,876. Cleveland showed a population in 1880 of 160,146, and in 1890, 261,353. In 1880 Buffalo had 155,134; in 1890, 255,664.

EFFECT OF SEWAGE ON LAKE WATERS.

The modern studies all indicate that when organic matter in increasing quantities is continually poured into a body of fresh water, a point is quickly reached beyond which the body of fresh water. whether it be lake, pond, or running stream, has no power of further assimilation. Chemical analyses of the waters of the Great Lakes show a gradually increasing contamination during the last fifteen or twenty years. The evidence is multiplying that, with the present increase in population, the Great Lakes, if they continue to be used as common sewers, will soon become totally unfit for use as drinking water. When this time arrives one of two alternatives must be followed—either every source of water supply must be filtered or the sewage of the towns must be efficiently purified before it is allowed to flow into the lakes. In some cases the conditions are such that both remedies must be applied.

The question of the limit of permissible contamination of these waters is very likely to arise, either as to the number of bacteria, the microscopical forms, or the chemical constituents. The answer is, it will depend entirely upon the environment. If a given water is known to receive sewage, a very small quantity of organic matter, indicated either by the free and albuminoid ammonias or by the loss on ignition, may justly cast suspicion upon it. If, on the other hand, there is no sewage contamination and the organic matter present is clearly shown to be due to natural drainage from the surface of the ground, the ammonias and loss on ignition have very little significance. As to the number of bacteria, Dr. Koch, the originator of the method of gelatin cultures, laid down the principle that potable waters might show, when examined immediately on collection, as high as 1,000 bateria per cubic centimeter without condemning them. The more recent studies, however, tend to show that Koch's original figure was somewhat too high, and at present it is considered that a sanitarily unobjectionable water ought not to show more than 300 to 500 forms per cubic centimeter. When the number rises much above that amount the water is open to suspicion.

Bacteriological examinations of the water of the Great Lakes show that the water at Detroit is superior for domestic use to that at Buffalo. The difference must be ascribed to the vast amount of sewage poured into Lake Erie, and the incapacity of that body of water to purify itself thoroughly before reaching the Buffalo intake at the head of the Niagara River.

If space permitted, many analyses of the water of the Great Lakes might be quoted which show, on the whole, a gradually increasing contamination.[1]

One point of interest about the water supply of the city of Milwaukee may be noted. During the navigation seasons of 1892, 1893, and 1894 the United States Weather Bureau carried out an extended series of float experiments in order to determine the actual trend of the currents of the Great Lakes. As regards Lake Michigan, the experiments clearly show that there is a rapid whirl at the south end, with a strong current passing north along the east shore, while along the west shore the current flows south. This disposition of the currents undoubtedly favors the water supply of the city of Milwaukee, giving to that city water with less organic contamination than it would receive, either if there were no current or if the current set from the south to the north along the west side, bringing to Milwaukee the contaminated water of the Chicago lake front. As the currents now flow Chicago receives the contaminated water of Milwaukee.

At Chicago the barbarous practice of turning the sewage of a great city into the body of water from which the public water supply is taken has resulted so disastrously as to lead to the construction of what is known as the Chicago drainage canal, by which it is expected to deliver the greater part of the Chicago sewage into the head waters of the Illinois River, and so finally into the Mississippi. Partial investigations, made several years ago under the auspices of the Illinois State board of health, indicated a very rapid purification of the sewage-contaminated waters of the present Illinois and Michigan Canal as they flow to the south. The investigation has not been carried far enough to indicate what the results will be upon the Illinois River and the Mississippi when the project shall have been completed and the sewage of Chicago largely turned south. The known facts as to the increasing contamination of the Great Lakes would indicate the vast importance of determining the ultimate effect of such discharge. In considering such effect, moreover, one should bear in mind the difference between running streams and lakes with only slight currents.

DANGER OF WINTER TYPHOID.

As regards water supplies from the Great Lakes at places so far north as to render probable the closing of the lakes by ice nearly every winter, there is another serious view connected with taking water either contaminated or liable to be contaminated by sewage, which has thus far been generally overlooked. So long as the lakes remain open, usually the antagonisms of the aerobic forms of microbic life will be sufficient, except in cases of extremely severe contamination, to keep typhoid and other anaerobic forms mostly in subjection; but as soon as the lake surfaces are covered with ice an entirely new set of conditions

[1] The author has in preparation a paper on Water Supplies from the Great Lakes, in which full data will be given.

exist; the air is then excluded and the anaerobic forms develop at the expense of the aerobic. This undoubtedly explains the severe epidemics of winter typhoid which have occurred at Buffalo, New York; Lorain, Ohio; Windsor, Ontario; Ashland, Wisconsin; Duluth, Minnesota; Chicago, Illinois, and at a number of other places on the Great Lakes. The following are some of the particulars of these winter outbreaks:

In the latter part of February, 1894, on account of low water in the Niagara River, it became necessary to take the water supply of the city of Buffalo from an old inlet said to be in a current carrying the discharge from sewers higher up. From March 6 to 11, inclusive, the total number of typhoid cases reported was 36. On March 12, 26 new cases were reported. The next day the number was increased 100, and then by 88, 79, 52, and 25 on successive days, making a total of 406 cases from March 6 to 17, inclusive, and 370 cases in the six days from March 12 to 17, inclusive. These cases were mostly of such mild character that only 9 deaths were reported for the whole month. In March, 1893, only 4 deaths occurred, and in March, 1892, but 1.

The city of Lorain, Ohio, is located at the mouth of the Black River, which receives the sewage of Elyria, several miles distant. It also receives the sewage of Lorain, in which place sewers were first laid down in 1892, their use for water-closet drainage beginning in October or November of that year. The water supply of the town is taken from very near the end of the harbor jetties, where the sewage first has free access to the lake water. Lake Erie was closed with ice at Lorain during the months of January, February, and March, 1893. In March and April there was a serious epidemic of typhoid fever, 8 deaths occurring in a population of about 5,000. In 1895 the lake was again closed with ice during the months of February and March, and typhoid fever again became epidemic, there being 3 deaths in February, 2 in March, and 4 in April.

In February, 1896, typhoid fever became epidemic at Windsor, Ontario, a town on the Detroit River just opposite the city of Detroit. During the previous month of December, 1895, the total number of cases was 9; for January the total was 18; for February 82, and for March 13; making a total for the four months of 122. The cause of the outbreak is ascribed to the presence of the sewage of Walkerville in the Windsor water supply. The discharge of Walkerville sewage above the Windsor waterworks intake has been a source of controversy between Windsor and Walkerville for several years, and although more or less typhoid fever has existed at Windsor the outbreak in February, 1896, is the most serious winter epidemic thus far experienced there. As stated in the report of the Provincial Board of Health of Ontario, there was a severe freshet about January 25, 1896.

During the winter of 1894 a severe epidemic of typhoid fever occurred at Ashland, Wisconsin. Several hundred cases developed in a few weeks, and from the distribution there was every reason to ascribe

their origin to the condition of the city water supply, which is taken from Chequamegon Bay, an arm of Lake Superior, on which the city is situated. This bay is about 12 miles long, with an average width of 5 miles. It varies in depth from 8 to 36 feet. A large breakwater has been constructed to the northwest of the city, on the city side of which is located the mouth of the intake pipe of the public water supply, about a mile from the shore. This arrangement is unfortunate, because it permits the sewage and storm water of the city to flow directly over the mouth of the intake pipe.

In February, 1894, the ground was covered with 2 feet of snow. In the last week of the month there were heavy rains and warm weather, which in a few days melted all the snow and washed the accumulations of the winter into the bay. Typhoid fever broke out in from ten to fifteen days thereafter, and in a week after the first case made its appearance there were over 300 cases. The epidemic lasted about eight weeks, and finally terminated with 450 cases and 26 deaths. Bacteriological examinations of the water showed that it contained as high as 36,000 bacteria to the cubic centimeter. Typhoid germs were found in one examination, and the bacillus coli communis in every examination made. This experience has led the city of Ashland to construct a sand filtration plant.

A severe epidemic of typhoid fever occurred at Duluth, Minnesota, a few winters ago under conditions similar to those at Ashland.

We have noted the insanitary conditions at Chicago on a previous page. By way of illustrating the prevalence of typhoid in that city we may refer to the following table, showing the number of deaths from that disease in Chicago from January, 1890, to December, 1893, inclusive, taken from the annual reports of the Chicago department of health:

Number of deaths in Chicago resulting from typhoid fever.

Month.	1890.	1891.	1892.	1893.
January	53	67	311	41
February	136	61	187	30
March	103	71	76	41
April	45	136	56	58
May	32	408	70	56
June	107	167	55	60
July	86	200	211	55
August	115	182	179	76
September	85	198	138	86
October	72	171	92	81
November	67	150	67	43
December	47	186	47	43
Total	1,008	1,997	1,489	670

The above table shows that typhoid fever was epidemic in Chicago in February and March, 1890, in April, May, June, and July, 1891, and in January and February, 1892. All these outbreaks, as well as the general high typhoid death rate, must be attributed entirely to the polluted water supply. The next year, 1893, was the year of the Columbian Exposition, and much greater efforts were made in that year to insure proper sanitary conditions in Chicago. That these efforts were well directed is shown by the great reduction in the typhoid death rate for that year.

In regard to typhoid fever, it may be assumed as axiomatic that it is a disease of the fall months, which under normal conditions attains its maximum in October and November. If, then, we find it seriously prevalent during the winter months, we must assume the existence of unnatural—and as regards the cases just presented, unnecessary—conditions. So far as known, the reason for its excessive development in cold weather is the one already given. As to the validity of this reason, it may be pointed out that similar winter outbreaks have occurred at Zurich[1] and Geneva, Switzerland. The evidence is therefore now so far multiplied as to render it practically certain that a winter outbreak of typhoid fever means not only sewage contamination of the water supply, but the existence of conditions different from those ordinarily obtaining while the lakes are open. Hence the several outbreaks of winter typhoid, of which we have record in the Great Lake cities and towns are, aside from others, a valid reason why sewage treatment of some sort is rapidly becoming imperative at the Great Lake towns.

AMERICAN SEWAGE-DISPOSAL PLANTS.

MAINE.

Augusta, State Insane Asylum.—So far as known, the credit of the first attempt at sewage irrigation in the United States belongs to Mr. C. B. Laken, treasurer of the State Insane Asylum at Augusta, Maine, who carried out a system of irrigation there about 1872. From a description in the Seventh Annual Report of the State Board of Health of Massachusetts (1876), it is learned that the sewage, which then amounted to about 7,000 gallons per day, first passed by gravity into large tanks, where it was mixed with absorbents—straw, leaves, muck, etc. The solid parts were from time to time carted onto land, while the liquid portion flowed off, to be used for irrigation. In the summer of 1875 an irrigated area of a few acres yielded three crops of fine hay. A portion of the sewage was also used in irrigating a vegetable garden. It is understood that after the death of Mr. Laken this irrigation was abandoned.

NEW HAMPSHIRE.

Concord, State Insane Asylum.—The sewage of this asylum was used for irrigation about the same time as that of the Augusta asylum. In

[1] For an account of an outbreak of winter typhoid at Zurich, Switzerland, see Mr. Preller's paper on The Zurich water supply, etc.: Proc. Inst. Civ. Eng., Vol. CXI, pp. 257-295.

this case it was necessary to pump the sewage to the irrigated area. The Eighth Annual Report of the State Board of Health of Massachusetts states that, although the crops were very much increased in value, the sewage had not been disposed of at Concord in the systematic way which would be necessary in dealing with larger quantities. It is not known whether this irrigation is now in use or not.

Rockingham County Poor Farm.—A sewage-disposal plant was first operated at the Rockingham County Poor Farm in 1895. The plant, which is designed to meet the needs of about 1,000 people, consists of two sets of collecting tanks, with filter beds, all so arranged as to admit of intermittent use, the whole inclosed in a building. Sewage is first received in a collecting tank 7 feet wide, 9.5 feet long, and 7 feet deep, where most of the sludge is deposited. The sewage then passes into a second tank, about half the size of the first, and connected therewith at the bottom. The effluent from the second tank flows upon a filter bed of coarse sand, 22 or 23 feet square and 5 feet in depth. The sludge is utilized for compost. The filter areas are ventilated by a force draft over and under them. From the information at hand it is inferred that this plant is a patented process, owned by the Glover Sanitary Sewage Company.[1]

MASSACHUSETTS.

Amherst.—This is a college town in the Connecticut Valley, with a population in 1890 of 4,512. A public water supply was constructed in 1879 and sewerage and sewage-disposal works in 1881. The sewers are on the separate system. In the absence of a water course suitable to receive the sewage, it was conducted to a settling tank, from which the liquid matter is drained onto land through ditches, and the sludge is periodically removed and spread upon land. Ordinarily the sludge is removed once a week by simply opening a valve and allowing it to flow into a bed excavated in the sand, where the water rapidly drains away.

About three-fourths of the sewage of the town is treated in this way, the remainder going to a field having a sandy soil, where it flows into absorption ditches. Three heavy crops of hay are cut yearly from the irrigated area, which previously gave only one light crop a year. This tract is not underdrained, and it is stated that the sewage does not give any trouble by collecting in hollows. The field has a slight slope.[2]

Brockton.—A good recent example of intermittent filtration pure and simple may be seen in the works recently constructed at Brockton, Massachusetts, a shoe-manufacturing town a short distance southwest of Boston, with a population in 1890 of 27,294. Waterworks were completed in 1880 and 1881, but a separate system of sanitary sewers was not put in operation until the latter part of 1894.

[1] Refer to Eng. and Bldg. Record, Vol. XXXIII, May 9, 1896.

[2] Refer to Twenty-fifth Ann. Rept. Mass. St. Bd. Health; Sewage Disposal in the United States; and Eng. News, Vol. XXVIII, July 21, 1892.

A.

B.

BROCKTON, MASSACHUSETTS, FILTRATION FIELDS.

A, Turnips and sweet corn; *B*, Pease, sweet corn, and beans.

By the application of meters the use of water at Brockton has been kept quite low. For the year ending November 30, 1894, the average daily consumption per capita was only 24.3 gallons, the highest figure being 39.4, for the month of June, and the lowest 18.7 gallons, for March. In the design of the sewers Mr. Snow, the city engineer, has made allowance for a daily consumption of 60 gallons per capita, as well as for a possible leakage by infiltration into the sewers. The main outlet sewer leading into the receiving reservoir is of brick, egg-shaped, varying from 26 by 39 inches to 22 by 48 inches in size, and about 2 miles long. The leakage by infiltration into the outlet sewer is estimated at about 120,000 gallons per day ordinarily, and in flood time at probably 350,000 gallons.

Inasmuch as there was no area available on which sewage could be delivered by gravity, it was necessary to raise the sewage to the filtration area by pumping. The force main provided for this purpose is of 24-inch cast iron, 16,640 feet in length, and rises 34.5 feet from the pump to the terminal chamber.

The filter area comprises some 30 acres, laid out in 23 beds. The soil of this area is mostly sand for the depth of several feet, but varies considerably in its mechanical constituents. In constructing the beds the natural material was not disturbed except at the surface; on 12 of them the sand was stripped from the subsoil; on 5, a thin layer of subsoil has been allowed to remain, and 6 of the beds have surfaces partly of the top sand and partly of subsoil. The general method of constructing these filter areas is the same as that followed elsewhere, and need not be especially referred to at length. The cost of the disposal works at Brockton is stated at $209,772, of which $59,536 was for the disposal area proper. The main items in the cost of the disposal area are 3,046 square yards of grubbing at $2 per yard, amounting to $6,092; 85,830 cubic yards of excavation in the filter beds, at 23 cents per yard, costing $19,739; trenching for and laying sewage-distributing pipes and underdrains, $12,631; land damages, $9,234. The balance of the $59,536 is made up of miscellaneous small items.

The experience with the sewage beds at Brockton has indicated that furrowed beds are far preferable for winter disposal to flat beds. During the winter of 1894 several of the beds were left with level surfaces, but the surface froze to such an extent on these as to prevent the sewage from penetrating them, whereas beds which had been furrowed the preceding fall took sewage readily during the entire winter. Accordingly, in the winter of 1895–96 all the beds in use were furrowed and no trouble was experienced during that season from freezing. The following, from the reports of the city engineer of Brockton, gives the average amount of sewage disposed of from month to month and its temperature as it reaches the beds.

Average amount and temperature of sewage received at Brockton sewage-disposal works.

Month.	Gallons per day.		Temperature.	
	1895.	1896.	1895.	1896.
			° F.	° F.
January	215,000	474,000	42.6	43.5
February	109,000	568,400	40.6	42.6
March	142,000	648,500	39.5	42.4
April	250,000	475,100	42.3	45.0
May	338,000	321,900	53.5	52.1
June	228,000	381,700	60.1	56.3
July	195,000	322,800	60.8	59.9
August	273,000	365,900	64.0	62.2
September	275,000	527,100	64.0	61.0
October	488,000	600,100	57.0	57.4
November	474,000	616,000	51.0	54.1
December	525,000	599,000	48.0	49.9

According to the report of the Massachusetts State board of health for 1895, the chemical analysis of the sewage and effluent from the underdrains at Brockton, made February 12, 1895, resulted as follows: Of the sewage, the total residue amounted to 84.4 parts per 100,000, of which 40.2 parts were dissolved and 44.2 parts suspended; the total loss on ignition was 38 parts, 12.4 dissolved and 25.6 in suspension; the free ammonia amounted to 3.46 parts per 100,000; the total albuminoid ammonia to 0.91 part, of which 0.244 was dissolved and 0.066 part in suspension; chloride amounted to 9.05 parts; nitrogen, as nitrates and nitrites, nil; the oxygen consumed in an unfiltered sample was 8.56 parts per 100,000, and in the filtered sample 3.12 parts per 100,000; the iron present in an unfiltered sample was 0.32 part, and in a filtered sample 0.08 part per 100,000. The hardness was 6.4.

The effluent of the same date showed an entire absence of turbidity and sediment, while the sewage was thick and contained a heavy black sediment. On Nessler's scale the colors showed 0.01; the residue on evaporation was 4 parts per 100,000; free ammonia, 0.0248 part; albuminoid ammonia, 0.0038; chlorine, 0.75 part; nitrogen as nitrates, 0.045 part; nitrites, nil; the oxygen consumed amounted to 0.024 part per 100,000; hardness, 0.6; and iron entirely absent. In regard to this effluent, it is proper to remark that it is stated to contain a large amount of ground water.

The design at Brockton includes a number of refinements, such as automatic arrangements for gaging the flow of sewage, which are very creditable to the city engineer, Mr. Snow, as well as to the municipal authorities of Brockton in general. Considering the scientific way in which the work there has been started, there is no reason why the

degree of purification to be attained should not be very high, especially since the works are to be operated as intermittent filtration areas only, and we may hope in the future to obtain from Brockton further information of value and interest to all concerned in works of sewage disposal.

During the year 1896, notwithstanding the additional cost of considerable experimental work, the total cost of labor at disposal works was only $2,195.21, or at the rate of $12 per million gallons of sewage treated. This sum included several items, such as setting of trees, grading about building, and pipe testing, which were in the nature of permanent improvements. Labor expended on surface of beds amounted to $932.03; for tending gates, $254.98; and for removing snow, $51.04; a miscellaneous item of $295.40, and a few others making up the remainder. Probably where these works are more fully established the cost of a treatment which yields a very fair effluent will not exceed $7 or $8 per million gallons treated; or, taking into account the value of the crops raised, the works will be about self-sustaining.

In his annual report for 1896 Mr. Snow has given a considerable amount of interesting information as to the operation of the Brockton plant. From this report it is learned that a variety of crops was planted on the beds receiving both sewage and sludge, such as pease, beans, tomatoes, sweet corn, cabbages, and turnips. Some of the conclusions derived from last year's experience are as follows: Pease and beans it is considered will do best if planted on level beds rather than on mounds. The pea crop last year was successful, one of the leading hotels of Brockton taking the entire product. Beans are stated to have failed. Sweet corn, which takes a large amount of sewage and demands but little attention, should be planted 4 feet between rows and in hills 3 feet apart in the rows. Cabbage requires more care than sweet corn, and when sludge is applied to the surface of the bed the same must be irrigated as though the bed were not cropped. It is considered that on a coarse sand or gravel soil with a level surface turnips should receive large doses of sewage, while with heavier soil small doses and a ridged surface will give the best results. Turnips appear to require considerable moisture during the first growth and but little after the root is formed. Six beds were planted with field corn on May 10. The crop was cultivated on June 1, and again about July 1, with a horse hoe. All the beds did well, the yield of one amounting to 144 bushels of ears per acre, or about 70 bushels of shelled corn.[1]

Gardner.—This place is a manufacturing town, situated in the central part of the State, on a divide between the Connecticut and Merrimac rivers. The population in 1890 was 8,424. A sewage-disposal plant by intermittent filtration was constructed in 1891, in conformity with plans approved by the Massachusetts State board of health. This board

[1] Refer to Ann. Repts. of City Eng. of Brockton; Repts. Mass. St. Bd. of Health; and various articles in Eng. News.

required sewage purification at Gardner, because turning sewage into the only available water course would probably create a nuisance. The tract purchased by the town for the disposal area contained about 17 acres of sand and gravelly soil. Much of the material is too fine for efficient filtration. This was overcome by making filter beds largely artificial, they being formed of selected porous sand and gravel from the material. At present there are twelve thoroughly underdrained filter beds, with a total area of 1.04 acres, two supplementary beds not underdrained and with a total area of 0.37 acre, also two other small underdrained beds, containing altogether 0.14 acre. One of the small beds is used to receive sludge from the sludge tank.

The filter beds at Gardner are smaller than those used at Marlboro, Framingham, and other places in Massachusetts, described further on. The sewage is delivered upon the beds by troughs, and each bed is provided with an overflow to prevent washing away the banks in case the sewage should at any time rise too high.

The results obtained at Gardner are said to be satisfactory in summer, but in winter the area is too small for efficient filtration, a difficulty which can be remedied by providing a larger area. The sewage reaches the filter area during the winter at a temperature not much above 40° F.

The cost of preparing beds with piping was about 12 cents per square foot of area. The total cost, including tanks and accessories, was about 14 cents per square foot of filter areas.[1]

Greenfield.—This place had a population in 1890 of 5,252. Sewage has been used for irrigation upon a meadow owned by a private party since 1882. As originally designed, the sewage was systematically distributed over the meadow, but during the last few years, since the death of the former owner, apparently but little effort at such distribution has been made. In consequence, recent statements at hand indicate that the sewage has caused a nuisance.

Lenox.—This place had a population in 1890 of 2,889. A combined system of subsurface and surface irrigation, preceded by tank sedimentation, was adopted in 1876, at which time the population was probably somewhat less than 2,000. The total area originally employed was only about 1½ acres. In October, 1888, a new subsurface-disposal area was placed in operation, which, however, did not cover the whole 17 acres purchased. As to recent results no information is at hand. Lenox enjoys the distinction of being the first town in Massachusetts to construct sewage-disposal works.[2]

Marlboro.—Population in 1890, 13,805. The city is situated on the dividing ridge between the Sudbury and Assabet rivers. The greater part of the drainage, however, naturally flows into Sudbury River,

[1] Refer to Twenty-fourth Ann. Rept. Mass. St. Bd. Health, 1892; Sewage Disposal in the United States, 1894; and Eng. News, Vol. XXIX, Feb. 16, 1893.

[2] Refer to Twenty-fifth Ann. Rept. Mass. St. Bd. Health; Sewage Disposal in the United States; and Eng. News, Vol. XXVIII, July 14 and 21, 1892.

from which Boston takes a portion of its water supply. The city of Boston, therefore, had a direct interest in so disposing of the Marlboro sewage as to leave the Sudbury River unpolluted, and, after some negotiations, agreed to pay $62,000 toward constructing the sewage-disposal plant. The sewage flows to the disposal fields by gravity. The total area purchased by the city is 62 acres, upon which forty-four beds for the filtration of sewage and six similar beds for sludge disposal, all covering with their dividing embankments a total area of about 37 acres, have been laid out. Thus far four sludge beds and thirteen sewage beds, or a total of about 11.3 acres, have been prepared for use. The material, which is for the most part a somewhat fine, porous sand with an effective size of 0.12 to 0.14 millimeter, has been thoroughly underdrained by means of parallel lines of 4-inch pipes laid with open joints 50 feet apart and about 6 feet beneath the surface. Filter beds were prepared for use by the removal of the top loam and the leveling of the surface of each at a convenient elevation.

The principal industry at Marlboro is the manufacture of boots and shoes; and, aside from the wastes of the manufacturing establishments, the sewage is ordinary city sewage, varying in strength with the amount of ground water entering the sewers, which were constructed on the separate system. No underdrains were laid beneath the sewers, and during wet seasons a large amount of ground water gains access to them through the joints. The total length of sewers laid to the end of 1895 was a trifle over 22 miles. The amount of sewage is not definitely known. A measurement on May 12, 1892, indicated about 30,000 gallons per day; on May 25, 1892, after heavy rains, the flow was 790,000 gallons per day. No attempt has thus far been made to raise crops on the filter areas.

The results obtained in purification have been satisfactory; over 95 per cent of the organic matter, as represented by the albuminoid ammonia, having been removed. The winter temperature of the sewage as it reaches the fields is from 39° to 42° F. The winter experience indicates that the beds work much better when ridged—as seen in Pl. IV, showing the filter areas at Pawtucket, Rhode Island—than when left level.

It has not been the custom to employ a man constantly in caring for the sewage disposal, but only from time to time as required to change the flow of sewage and to remove scum from the surface of the beds, etc., payment being made by the hour for the time actually consumed. The cost of all work on account of the disposal plant during the year 1893 amounted to $497.19. There seems to be no doubt, therefore, if the amount of labor was sufficient, that the town could recoup itself for the expenditure by preparing more beds and raising crops thereon.[1]

[1] Refer to Twenty-fourth, Twenty-fifth, and Twenty-seventh Ann. Repts. Mass. St. Bd. Health; Sewage Disposal in the United States; and Eng. News, Vol. XXVIII, Aug. 25, 1892.

Concord, Massachusetts Reformatory.—The sewage of this institution was originally discharged into the Assabet River at a point near the institution, but in 1883 an act was passed by the Massachusetts legislature authorizing an expenditure of a sum not exceeding $5,000 for the disposal of the sewage by some other method. The plans adopted include arrangements for pumping the sewage upon an adjacent field, where it is used in broad irrigation of grass and corn crops, as well as other tilled crops to some extent. The soil of this field is light, free, and sandy, with the ground water at a considerable depth below the surface. Portable troughs are used for distributing the sewage to different parts of the field.

The labor is all done by convicts. Assuming a fair valuation for the labor actually used under normal conditions of employment, we have the following as the approximate annual cost of operation: 55 tons soft coal, at $4, $220; salary of attendant, $600; repairs and sundries, $80; total, $900.[1]

Medfield.—Population in 1890, 1,493. Sewers and sewage-disposal works were constructed in 1886, the sewage disposal including preliminary sedimentation and upward filtration through excelsior supplemented by intermittent filtration through natural soil. The material of the filter area is mostly coarse gravel, with ground water about 10 feet below the surfaces of the beds, which are underdrained. There are four beds which, as a general rule, take the sewage in turn for two days. The filter area consists of 1 acre of ground, graded nearly level. The entire cost of the disposal works, including cesspool, pipe from cesspool to outlet, earthwork, engineering, superintendence, and profit to contractor, was about $1,000. The annual expense of maintenance is stated at about $30 a year, the labor being chiefly to change regularly the gate whereby the sewage is diverted from one portion of the filtration area to another.

Analyses of the effluent from the Medfield area, made in October, 1893, showed that the quality was still quite as good as indicated by analyses made when the works were first operated in 1887.[2]

Mystic Valley.—These works, which are operated by chemical precipitation purely, were constructed in 1887 and 1888 by the city of Boston in order to protect the Upper Mystic Lake, whence the water supplies of the Charlestown district of the city of Boston and of the towns of Chelsea, Everett, and Somerville are derived.

Near the head of Upper Mystic Lake, in Winchester and Woburn, there are about a dozen tanneries, the drainage from which formerly passed directly into the lake, which was also considerably polluted by house drainage flowing into the Abbajona River, the influent stream of Mystic Lake. In 1878 a sewer was constructed intercepting all this objectionable drainage and delivering it into Lower Mystic Lake, which

[1] Refer to Seventh Ann. Rept. Mass. St. Bd. of Health, Lunacy, and Charity, Supplement, 1886.

[2] Refer to Nineteenth Ann. Rept. Mass. St. Bd. Health; Jour. Assoc. Eng. Socs., Vol. VII, July, 1888; and Eng. and Bldg. Recd., Vol. XVIII, 1888.

is subject to tidal action. Its delivery there, however, led to controversies between the adjoining towns and the city of Boston, which were finally settled by the construction of the Mystic Valley Chemical Purification Works. Inasmuch as the chief object of these works was to purify manufacturing wastes, they may easily be placed first among successful works of this character. A general view of the works is given in fig. 1 of Water-Supply and Irrigation Paper No. 3.

The works consist in detail of a pump well, connected with the main sewer by a branch sewer of brick, a sewage pump and engine, engine house, four settling tanks, a sludge well, sludge pump, and a series of settling basins for receiving the sludge. In the engine house there are three vats so arranged that the precipitant is fed from the middle vat, which is placed lower than the other two, in which the precipitant is dissolved. These vats are provided with steam coils for heating the water used and with a stirring apparatus driven by the engine. The precipitant is fed to the sewage as it flows from the branch sewer into the pump well, where the process of pumping thoroughly incorporates the chemicals. From the pump the sewage passes into the settling tanks. It is then allowed to remain quiescent for about three hours, when it is found that the sedimentation process is complete. The clarified effluent is then drawn off by removing stop planks. The sludge is pumped, as necessary, into a flume which conveys it to the sludge basins shown in fig. 1 of Water-Supply and Irrigation Paper No. 3.

The cost of the works, including the preparation of the sludge basins, was $10,410.

For the thirteen months ending January 31, 1892, the total quantity of sewage pumped and treated was 133,102,028 gallons. Sulphate of alumina is used as the precipitant, and during this period the total quantity consumed was 331,890 pounds; the amount of coal, 210.7 tons. The quantity of sludge removed during the same period was 2,334 cubic yards, which was mostly carted away by a neighboring farmer for fertilizer. The rate of application of participant was 1 part to 3,354 parts of sewage or 1.24 net tons per 1,000,000 gallons of sewage.

The operation of this plant by the city of Boston ended July 18, 1895, at which time the Metropolitan Sewage Commission assumed control of it. From January 1 to July 18, 1895, the average daily amount of sewage pumped and treated was 376,400 gallons, requiring 143,540 pounds of sulphate of alumina. The Metropolitan Commission has made the Mystic Valley sewer a part of the Metropolitan sewerage system and discontinued the chemical treatment. The first annual report of the Metropolitan water commissioner for the year ending January 31, 1896, states that this plant required the service of about 14 men to operate it, and that its discontinuance removes an annual expense of about $20,000.[1]

[1] Refer to annual reports Boston Waterworks; First Ann. Rept. Met. Water Com.; Sewage Disposal in the United States; a paper by W. F. Learned in Jour. Assoc. Eng. Socs. for June, 1888; and Eng. and Bldg. Recd., Vol. XIX, 1889.

Natick.—Natick is about 17 miles from Boston, on the Boston and Albany Railroad, and had in 1890 a population of 9,118. A public water supply has been in use since 1874. In 1885 Eliot C. Clark, engineer to the Massachusetts drainage commission, recommended that a joint sewage-disposal system be built for the towns of Natick, Framingham, and Ashland, and for the Sherborn Prison, situated a short distance from South Framingham, the principal village in Framingham town, with disposal on a gravelly and sandy area, which has since been selected by Framingham and Natick for this purpose. Mr. Clark's idea was that these several towns and the public institution should act in concert, but, unfortunately, the difficulty of reconciling local differences prevented the adoption of his scheme. The two towns of Framingham and Natick have, however, acted separately in utilizing the area selected by Mr. Clark. Framingham completed its sewerage and sewage-disposal system in 1889, while the Natick system was put in operation only during the year 1896.

The indifference of Natick as to sewage purification has been for a number of years particularly flagrant by reason of the flow of a considerable portion of the town sewage into Pegan Brook, a tributary of Lake Cochituate, one of the main sources of the Boston water supply. Negotiations have been had between the city of Boston and Natick looking to purification of this sewage, but without effect. Finally, a few years ago, the city of Boston constructed, at its own expense, on a sandy plateau adjacent to the lake, a filter area upon which the ordinary flow of Pegan Brook was diverted and purified by intermittent filtration. Some portion of the flood flow of the brook has, however, necessarily gone into the lake whenever heavy rains occurred.

The construction of the Natick works began in 1895, under the direction of Samuel M. Gray as engineer. The detailed plans prepared by him provide for bringing the sewage by gravity to a pumping station through a 30-inch circular brick sewer and 24-inch cast-iron pipe with lead joints. The 24-inch pipe is used where the main sewer passes near the head of Lake Cochituate, in order to prevent any possible leakage into that body of water.

The pumping station is provided with a screen chamber, receiving gallery, storage reservoir, pump wells, etc., and the usual accessories of such a plant. According to a statement made by Mr. Gray, when the sewage reaches the screen chamber it passes through iron bars placed three-quarters of an inch apart, after which it may be turned, as desired, either into reservoirs for storage or into a pump well, from which it may be raised directly to the filter areas. In this latter arrangement the pump can be regulated to take the flow as it comes, thereby saving the lift which would otherwise be necessary if it went to the reservoir. The total capacity of the reservoir is 500,000 gallons. The intention is that the night and Sunday flow be stored in the reservoir.

The sewage is delivered to the filter areas through 8,000 feet of 16-inch cast-iron force main, laid on a grade throughout its entire length, for the purpose of permitting the contents to flow entirely back into the pump well in case it becomes necessary to clean the interior surface of this pipe.

The tract of land appropriated for the disposal works was originally covered with a small growth of wood brush. The soil is sandy and generally well adapted to filtration, although there are thin layers of sandy clay in some of the beds which, as Mr. Gray believes, will make it necessary to lay underdrains. The effluent from the underdrains will be discharged into a small stream which enters the Sudbury River below the outlet of Lake Cochituate. It will be noticed, therefore, that the sewage, as well as the effluent, is entirely diverted from Lake Cochituate, in the same way as in the neighboring town of Framingham.

The entire plant as designed includes the preparation of 12 acres of filters to be underdrained with 3-inch tile, laid on a grade of 2 feet in a hundred, in lines 36 feet apart. The work in 1895 included the preparation of 2 filter beds of 1 acre each, from which the underdrains were omitted. Another bed was completed in 1896 with underdrains.[1]

Norfolk County Jail.—This institution has a land disposal plant of some sort, particulars of which, however, are not at hand.

North Brookfield.—The village of North Brookfield is situated in the town of Spencer, in which a water supply was introduced in 1883. The population of the whole town in 1890 was 8,747, having increased from 7,466 in 1880. North Brookfield proper, however, has a population of only about 3,000, which can be ultimately connected with the main sewer as built in 1893, when sewage-disposal works were also built, the system adopted being that of broad irrigation. According to a statement of Mr. Craig, the supervising engineer of the work, published in the Engineering News of March 22, 1894, it would appear that there are about 20 acres of a farm owned by the town which is well adapted to broad irrigation, the soil being naturally very light and dry, and not yielding heavy crops under ordinary methods of farming. In order to reach the highest point of this area it was necessary to employ an inverted siphon about 1,600 feet in length, which has been successfully constructed and operated, and a profile of which may be seen in Engineering News at the place indicated.

This sewage farm was first in working order in November, 1893, and no statements as to the results of broad irrigation are yet at hand. It is considered, however, that with the favorable soil of the locality very satisfactory results may be attained. This farm is also interesting as being very inexpensive, the total cost of the entire system of sewers, including flush tanks, screen chamber, and labor necessary in preparing the farm, being only $9,700. The sewage is first received in a storage tank, from which it is discharged intermittently to the farm.

[1] Refer to Eng. News, Vol. XXXV, June 4, 1896.

Pegan Brook.—Some general statements in regard to the filter areas constructed for the purpose of excluding from Lake Cochituate the raw sewage of Natick, which previous to the construction of the Natick sewage-disposal works flowed into Pegan Brook and thence directly into the lake, have been made in discussing Natick (pp. 50–51), and a few detailed statements may now be added. The filter areas are three in number, constructed by removing the soil and placing it in embankments 5 feet high around and between the beds. The filter material, to the depth of 8 feet, is mostly sand, about as fine as ordinary plaster sand. The three beds are about 2, 0.75, and 1.25 acres, respectively. Their elevations are 140, 144, and 146.8 feet above the waterworks datum, 134.4 feet being the elevation of low water in the lake. The lowest bed, with an area of about 2 acres, is not underdrained. Water percolates freely through the sand, which is stated to be excellent filter material. Underdrains about 100 feet apart and 8 feet deep are laid beneath the upper beds. They consist of 8-inch vitrified tile pipe, laid with open joints wrapped with canvas. The underdrains were chiefly designed in order that samples of the effluent may be obtained for examination. An earth dam for diverting the water of the brook onto the filter beds and a pumping plant were included in the plans. The entire cost is stated at $12,585.11.

The Pegan Brook filters are of special interest, because, so far as known, they are the first filter areas ever constructed for the filtration of a polluted feeder to a natural lake which is the source of a public water supply. There may possibly be some such arrangement in use abroad, but certainly this is the first plant constructed for such purpose in the United States.[1]

Waltham, School for the Feeble-Minded.—An intermittent subsurface irrigation or filtration plant was constructed at this State institution about 1890. In 1893 permission was granted to connect the sewers of the school with the sewerage system of the city of Waltham, since which time it is understood that the disposal area has been out of service.

Sherborn Prison.—A number of years ago arrangements were made for disposing of the sewage of this State institution by subsurface irrigation. Information as to the extent and success of the project is not at hand. The works are believed to be out of use.

South Framingham.—The sewage-disposal works at South Framingham, Massachusetts, are of considerable interest as involving both broad irrigation and intermittent filtration, and also because real progress has been made here in raising crops on filter beds. Unfortunately, at South Framingham, as well as at about all the other sewage farms in the United States, no one has yet attempted to keep statistics as to the daily flow of sewage, the amount applied, and other important facts, data which must be at hand before definite conclusions can be

[1] Refer to Ann. Rept. Boston Waterworks for 1893, and Eng. and Bldg. Record, Vol. XXIX, Apr. 28, 1894.

A.

B.

SOUTH FRAMINGHAM, MASSACHUSETTS, SEWAGE FARM

A, Sewage inlet to filter (field of growing corn in left foreground, larger corn in distance); *B* Portion of cabbage field.

drawn as to the efficiency of the process at any given point. In favor of South Framingham it may be said that the cropping on the filter beds has been very successful, but as the results have been referred to on page 43 of Water-Supply and Sewage Irrigation Paper No. 3, a further account here is unnecessary.[1]

Wellesley College.—Previous to 1892 the sewage was mostly disposed of by passing it through small and imperfect artificial filters of peat and gravel, but, as the results were unsatisfactory, new works were constructed in that year for treatment by intermittent filtration. Additions to the works were made in 1893. The sewage to be treated is that of about 500 persons, for which purpose a filtration area of 1.55 acres has been provided.[2]

Westboro.—Population in 1890, 5,195. Construction of a sewerage system began in 1891. About 33 acres of land located on the right bank of the Assabet River have been acquired by the town for sewage-disposal purposes, nearly one-half of which may be classed as either swamp or meadow, subject to flooding at times of high water. The sewage is conducted to a settling tank on the disposal area, built in two compartments, with a total capacity of less than 1,000 gallons. Two filter beds, with a total area of a little over 2 acres, were prepared in 1892 by stripping off most of the loam and filling with coarse gravel, the material beneath being a fine compact sand nearly impervious to water. The information at hand indicates that this plant has not worked well.[2]

Worcester.—To show the relative degree of purification obtained by chemical processes of treatment in comparison with intermittent filtration and irrigation processes, brief reference may be made to the results obtained by the works at Worcester, Massachusetts, which may be considered not only the best example of a chemical-purification plant on a large scale thus far completed in the United States, but which, in the opinion of those competent to judge, is as good an example of this method of purification as can be found anywhere. The fact that it has not been successful in entirely mitigating the pollution of the Blackstone River, into which the effluent from the Worcester works flows, must be attributed to inherent difficulties of the chemical process, and not to any lack of proper application of that process at Worcester. Indeed, the author takes pleasure in saying that after having examined the large purification works abroad, as well as a greater portion of those in this country, he has nowhere seen a better example of the chemical treatment, pure and simple, than that at Worcester.

According to the report of the superintendent of sewers for the year 1895, it appears that in 1894, as an average, these works removed 49.35 per cent of the total amount of organic matter present in the sewage as determined by evaporation; of the amount in suspension, 94.45 per

[1] Refer to Report of Com. on Drain. and Sew., etc., Nov., 1889; several articles in Eng. News; and Sewage Disposal in the United States.

[2] Refer to Twenty-fifth Ann. Rept. Mass. St. Bd. Health, 1893.

cent was removed; of the total amount, based on the albuminoid ammonia, 50.79 per cent was removed; of the amount in suspension, based on the albuminoid ammonia, 89.54 per cent was removed; the total amount by oxygen consumed was 43.84 per cent, and the amount in suspension by oxygen consumed 81.08 per cent.

Experience at Worcester indicates that different percentages were removed in the various seasons, as, for instance, in 1894 the total per cent of organic matter removed from the sewage as an average, from July to December, was, by evaporation, 55.02 per cent; the amount in suspension, also by evaporation, 95.76 per cent; the total amount of albuminoid ammonia, 53.78 per cent; the total amount by suspension in albuminoid ammonia, 94.36; total amount by oxygen consumed, 50.23 per cent; the amount in suspension by oxygen consumed, 92.42 per cent.

From December to July the total amount of organic matter removed by evaporation was 42.76 per cent; amount in suspension, 93.08; total amount by albuminoid ammonia, 46.63 per cent; amount in suspension by albuminoid ammonia, 83.26; total amount by oxygen consumed, 37.11; amount in suspension by oxygen consumed, 89.27 per cent.

The average analyses of the sewage for the year ending December 1, 1895, were as follows: Free ammonia, 1.16 parts per 100,000; total albuminoid ammonia, 0.518 part; dissolved albuminoid ammonia, 0.249 part; suspended, 0.270 part. The oxygen consumed in unfiltered sewage was 5.27 parts and in filtered sewage 2.91 parts per 100,000, and the chlorine, 5.98 parts. The average of the effluent for the same year was: Free ammonia, 1.008 parts; total albuminoid ammonia, 0.252 part, of which 0.228 part was dissolved, 0.024 part suspended. In unfiltered effluent the oxygen consumed amounted to 2.4 parts and in filtered effluent 2.27 parts, and the chlorine to 5.92 parts per 100,000. Taking the purification by percentage actually removed, we have, for the free ammonia, 13.02 per cent; total albuminoid ammonia, 51.63 per cent; dissolved albuminoid ammonia, 8.43 per cent; suspended albuminoid ammonia, 91.11 per cent; oxygen consumed, total, 54.35; in solution, 21.99; chlorine, 1.05 per cent. It will be noticed that the chemical process only moderately touches the free ammonia and the dissolved albuminoid ammonia.

The works at Worcester were constructed chiefly because of serious complaints on the Blackstone River as to the pollution caused by the Worcester sewage, which originally flowed into the stream in a raw state. The following gives the mean of a series of analyses of the stream as made by the Massachusetts State board of health in 1895: Color on Nessler's scale, 0.71 part per 100,000; total residue on evaporation, 22.15; loss on ignition, 5.18; free ammonia, 0.3246 part per 100,000; total albuminoid ammonia, 0.0898 part, of which 0.0597 part was dissolved and 0.0301 part was suspended; chlorine, 1.86 parts; nitrogen as nitrates, 0.0267 part; nitrogen as nitrites, 0.0063 part; hardness, 7.3.

A.

B.

WORKS AT WORCESTER, MASSACHUSETTS.

A. General view of precipitation tanks; *B*. Another view of precipitation tanks.

In considering these results it should be remembered that the sewerage system of the city of Worcester is a combined system, and that frequently at the time of heavy rains a considerable portion of the sewage flows into the Blackstone River entirely without treatment. The information in regard to the Worcester works is too extensive to be given in detail here. It may be found in the several annual reports of the city engineer and the superintendent of sewers of the city of Worcester, and also in the reports of the Massachusetts State board of health.

The litigation between the city of Worcester and the town of Millbury, a few miles down the river, on account of the pollution of the Blackstone River, may, however, be briefly mentioned by reason of its being the most extensive of legal proceedings involving stream pollution thus far taken in the United States. Without detailing all the steps, it may be stated that the objections of Millbury finally resulted in the passage of a mandatory act of the Massachusetts legislature requiring Worcester to purify its sewage before allowing it to flow into the Blackstone River. Under the provisions of this act the purification works were built and first operated in 1890.

In 1890 the population of Worcester was 84,655, while in 1895 it had increased to 98,678, and at the same time the pollution of the river was so bad that in the latter year Millbury again brought suit against Worcester. At the trial, in April, 1896, the case of the town of Millbury was supported by Allen Hazen, Col. George E. Waring, jr., Rudolph Hering, Mrs. Ellen H. Richards, and George W. Rafter, while Worcester's side was represented by Samuel M. Gray, Prof. William T. Sedgwick, Prof. H. P. Kinnicut, Charles A. Allen, Harrison P. Eddy, and F. A. McClure. The testimony touched nearly every phase of sewage purification and stream pollution. In a decree dated December 14, 1896, the presiding justice ordered that within three months Worcester should take steps to purify the stream. The preliminary steps to comply with this decree have been taken.

Worcester Insane Hospital.—These works were constructed in 1876, and have since successfully disposed of the sewage of about 600 people, the ordinary population of the hospital.

As shown on a previous page, some attempt has been made to dispose of sewage by broad irrigation at the State insane hospitals at Augusta, Maine, and Concord, New Hampshire, a short time before the sewage farm of the Worcester Insane Hospital was first operated. Neither, however, was entirely successful, and both have been abandoned. We must therefore give the credit to the authorities of the Worcester Hospital for instituting the first permanently successful sewage-irrigation farm in the United States.

The hospital building is situated on a considerable rise of ground, about 3,000 feet west of the main irrigation field, which includes 14 acres. There are also arrangements for drawing sewage along the line of the sewer leading from the hospital to the main field, which permits

the irrigation of a total of from 30 to 40 acres. The entire hospital farm includes 257 acres.

The work was mostly constructed by the inmates of the hospital and no statement of cost can be made.[1]

PLANTS PROJECTED IN MASSACHUSETTS.

Information as to the number of projected sewage-purification plants in Massachusetts has been obtained from the annual reports of the State board of health, 1890 to 1895, inclusive, as follows:

Andover.—This town submitted plans for sewage disposal to the State board of health for approval in 1895. The plans proposed were rejected as thoroughly impracticable, and the sewer commissioners were instructed in a communication dated October 10, 1895, as to the proper lines on which to develop sewage purification for that place.

Braintree.—The sewerage committee of this town submitted plans for sewage disposal to the State board of health in 1893. In its answer, under date of July 6, 1893, the board suggested that inasmuch as the towns of Braintree and Weymouth were contiguous and were near the sea, the interests of both communities might be served by united action in the construction of an outlet to tide water.

Concord.—The committee on sewage of this town asked the advice of the State board of health on a proposed plan of sewage disposal in 1894. Under date of January 3, 1895, the board replied that, judging from the outline presented, the plan proposed could be commended as well adapted to the needs of the town, and that a system of intermittent filtration on the area proposed would be a proper method of disposing of the sewage of Concord.

Danvers.—In 1895 the board of health of this town applied to the State board for advice as to the disposal of sewage of three morocco factories in that place. In its answer, under date of December 5, 1895, the State board of health suggested, as a line of investigation, that probably the sewage should be first conducted into large settling tanks, where the sludge would deposit, and from which the liquid could be pumped to a filter bed and the sludge be frequently removed from the tanks, to be disposed of presumably either by burying or for use as manure in agriculture.

Foxboro Hospital for Dipsomaniacs and Inebriates.—Information as to an intermittent filtration plant proposed for this State institution may be found in the Twenty-third and Twenty-fourth Annual Reports of the Massachusetts State Board of Health.

Leicester.—Plans for sewage disposal for this town were submitted to the State board of health in June, 1893. They included preliminary sedimentation and filtration, the sludge to be allowed to drain out in beds, after which it will be carted away for use in agriculture.

[1] Refer to the Forty-seventh Ann. Rept. of the Trustees of the Hospital for the year ending September 30, 1879.

Medfield Insane Asylum.—Plans for the disposal of the sewage of this State institution by means of intermittent filtration were submitted to the State board of health in 1892.

Pittsfield.—Chapter 357 of the acts of 1890 authorizes the city of Pittsfield to build a system of sewerage and sewage disposal, subject to the approval of the State board of health. The plans were presented to the board for its approval in 1891. They provide for the permanent disposal of the sewage by intermittent filtration, but permit a temporary discharge into the Housatonic River until June 1, 1900, after which date the sewage of the city must be treated before discharge, as provided in the plans.

Spencer.—This town was advised by the State board of health, under date of December 8, 1893, as to proper disposal of the town sewage by land treatment. The board pointed out that the wastes from the gas works which now enter the sewers of Spencer should be either excluded or so treated before admission as to remove all tarry or oily substances which would tend to clog the filters.

Bridgewater, State farm.—Under date of December 14, 1895, the State board of health advised the superintendent of the State farm at Bridgewater as to the purification of the sewage by land treatment, preferably by filtration through porous soil about 1¼ miles from the building.

Tewksbury.—The State board of health advised the authorities of this town in regard to land purification of the sewage under date of October 3, 1895.

Wakefield.—In 1892 the sewerage committee of Wakefield submitted to the State board of health plans for the sewerage and sewage disposal of the town, the sewage of the principal village of the town to be treated by filtration upon land, and the remainder of the sewage to be discharged into the main metropolitan sewer. In its answer to the application, under date of October 7, 1892, the State board of health gives general suggestions as to the best method of preparing the disposal areas.

At several other places in Massachusetts sewage-disposal works have been projected and are likely to be constructed in the next few years. The foregoing examples are sufficient to indicate the advanced state of sewage-purification questions in the Commonwealth of Massachusetts.

RHODE ISLAND.

Sewage-disposal works have been either constructed or projected in Rhode Island as follows:

Central Falls.—The present city of Central Falls was part of the old town of Lincoln, in Providence County. The population of the town of Lincoln for 1890 is given at 20,355. In 1892 a tract of land of about 35 acres was purchased for the disposal of the sewage of the western district of the city, at a cost of $20,000. The disposal plant, which for the present includes three filter beds of about one-fifth of an acre each,

was constructed in 1896. Additional filter areas are to be constructed as required. The sewage flows to the disposal grounds by gravity. The cost of the work of preparation to date, including settling tank, is is about $9,500.[1]

Pawtucket.—Pawtucket, with a population of 32,577, according to the State census of 1895, is divided into two principal drainage districts, known as the Blackstone River district and the Moshassuck River district. The sewers of both the districts are of the combined system, those of the first district amounting to 27.16 miles, and those of the second district to 7 miles. The filter plant is connected with the sewers of the second district, which includes an area within the city of 960 acres and an approximate population of 9,500; 110 acres of this

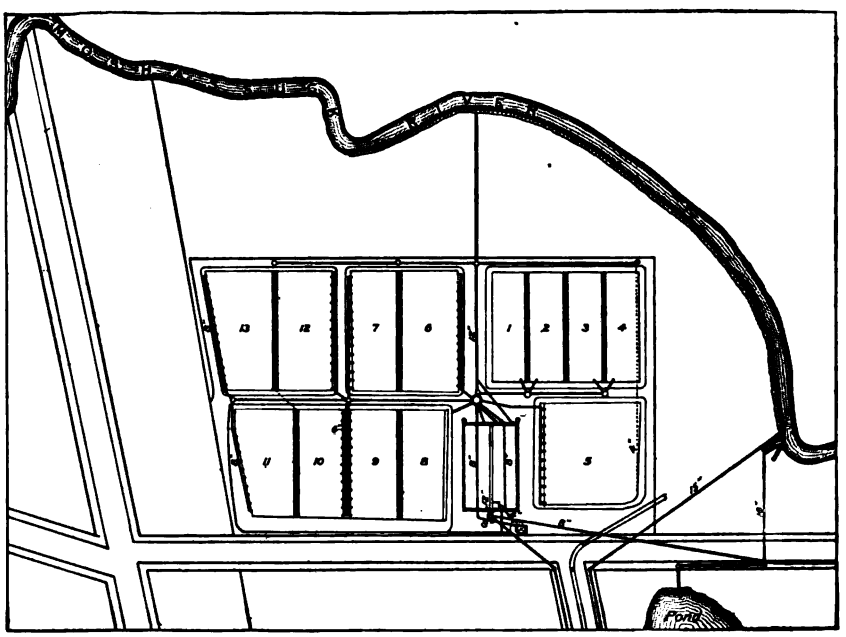


FIG. 4.—Plan of filter areas at Pawtucket, Rhode Island.

area is the most thickly settled portion of the city, having a stated population of 34 persons to the acre. Filter areas are located in the southern part of the city and border upon the Moshassuck River, as shown in Pl. IV. This stream is comparatively small, having an ordinary flow of from 30 to 45 cubic feet per second. It is very much polluted, both above and below the filter areas, by wastes from manufactories, and in view of future complications it was deemed best that the city should not be a party to this pollution. The filter areas, as already constructed, include a little less than 4 acres, about 2.4 acres being the actual area capable of receiving sewage. This is divided, as shown in fig. 4, into 13 beds, 4 of which are designed for sludge beds,

[1] Refer to Eng. and Bldg. Recd., Vol. XXXV, April 24, 1897.

FILTER AREAS AT PAWTUCKET, RHODE ISLAND, AS RIDGED FOR WINTER SERVICE.

and are laid out slightly lower than the other beds in order to receive the sludge from the bottom of the tanks.

Covered sewage tanks have been provided, into which the sewage is first received, and from which it is discharged upon the beds as desired. The sewage flows to these tanks from the city by gravity. Arrangements have also been made by which the flow of sewage can be shut off from the tanks automatically and turned into the storm overflow whenever the amount delivered is so increased by a storm as to tax the capacity of the tanks above the average or above any amount to which the apparatus has been adjusted. After the cessation of the storm and the consequent return of the sewage to the average rates, the gates to the settling tank open automatically, allowing the sewage to again flow into them. In ordinary use sewage is received into the tanks for about twenty-four hours and then turned upon the beds under irrigation at the rate of 100,000 gallons per acre.

Work was begun on the disposal areas in 1893. Generally speaking, the work at Pawtucket has been well carried out and the operation of the plant is successful.[1]

Cranston, State institutions.—The State institutions at Cranston, Rhode Island, include a house of correction, State almshouse, State hospital for the insane, State prison, the Sockanosset School for Boys, and the Oak Lawn School for Girls. They are situated in the midst of a tract of about 500 acres of land owned by the State. Sewage disposal by land treatment was first proposed at Cranston in 1884, and carried out in 1895, since which time it has been successfully operated.

The filtration is said to work well in winter, the sewage reaching the field ordinarily at temperatures of about 40°, 42°, or 43° F.[2]

Providence.—Sewage disposal on a large scale has also been projected for the city of Providence, which had a population in 1890 of 132,146. As the matter now stands, it is proposed to partially purify the sewage by chemical precipitation and discharge it into tide water at Fields Point. Main intercepting sewers have been under construction for the last few years with this end in view.[3]

Woonsocket.—Sewage-disposal works have also been projected for Woonsocket.

CONNECTICUT.

Bristol.—A recent example of a combination broad-irrigation and intermittent-filtration plant is at Bristol, Conn. The population of this town in 1890 was 7,382. In 1892 a number of suits were brought to restrain the discharge of crude sewage into a stream flowing through

[1] Refer to Eng. News, Vol. XXXV, January 2, 1896, where a very complete account by George A. Carpenter, city engineer of Pawtucket, designing and constructing engineer of these works, may be found.

[2] Refer to Seventeenth Ann. Rept. Bd. Charities and Corrections of R. I., 1895; also Eng. and Bldg. Record, Vol. XIII, March 4, 1896.

[3] The Providence sewage-disposal data are very extensive; for a digest of the same refer to Sewage Disposal in the United States.

the town. The suits have been held in abeyance pending the construction of sewage-purification works.

Plans for a sewerage and sewage-disposal system were prepared in 1892, but the actual work of construction was delayed about three years awaiting necessary legislation. Acting under the advice of Mr. McKenzie, the town's engineer, 80 acres of land were purchased at $35 per acre for the purpose of constructing filter beds and also for utilizing sewage by broad irrigation. The necessary sewers and a portion of the disposal area were constructed in the year 1895.

The filter areas as thus for prepared include about 6 acres. The material is coarse sand and gravel. Sewage is distributed to them by means of 15-inch and 12-inch carriers. The underdrains, so far as laid, are 8 inches and 6 inches in diameter and 25 feet apart. It is not intended to underdrain the irrigation area. The cost of preparing 6 acres of filter beds, with the necessary appurtenances, was about $9,000. No definite statements can yet be made as to the results of purification or irrigation at this place.

Danbury.—Population in 1890, 16,552. A few years ago the Wolf disinfecting process, which consists in dosing the sewage with sodium hypochlorite formed by a partial electrical decomposition of a solution of salt and water, was applied. The process, as applied at Danbury, proved inefficient, and suits were brought enjoining the city from discharging its sewage into Still River. The court recommended intermittent filtration, adjudged costs against the city, and required discontinuance of the discharge after May 1, 1897. Under these circumstances the town purchased an extensive tract of land, a portion of which is stated to have been prepared for use in intermittent filtration.[1]

Lake Wauremaug.—This lake, which is surrounded by a number of hotels and cottages, has abrupt, rough, and rugged shores, which render an economical, safe disposal of sewage somewhat difficult. Areas for land treatment are entirely lacking. Under these circumstances a committee of the State board of health in 1894 recommended the treatment of all human fæces and urine by a dry-earth system, and the treatment of laundry and sink wastes by filtration in trenches on sloping ground, somewhat after the method successfully used at Wayne, Pennsylvania. It is understood that these recommendations have since been carried out.

Litchfield.—Population in 1890, 3,304. The first sewage-irrigation field in Connecticut was inaugurated at this place in 1890. Area of same, 4 acres. No details as to method of operation or success attained are at hand.[2]

Manchester.—Population in 1890, 8,222. It is stated that a sewage-disposal plant by land purification has recently been constructed. No information as to details is at hand.

---

[1] Refer to Eng. News, Vol. XXXIV, August 29, 1895.

[2] Refer to Fourteenth Ann. Rept. Conn. St. Bd. Health, 1891.

Meriden.—The sewage-disposal works at Meriden furnish an example of combined irrigation and intermittent filtration. The population of Meriden was 21,652 in 1890. Waterworks were built in 1869.

The gradual extension of sewers having led to a considerable pollution of Harbor Brook, a small stream flowing through the central and lower part of the town, the question of sewage purification gradually became a leading one until a special committee was appointed, in 1891, to investigate and report on the general question. This committee submitted reports of engineers recommending broad irrigation, supplemented by intermittent filtration, on a tract of land of about 150 acres, which was subsequently purchased for this purpose. According to statements in Engineering News, the disposal area as originally planned included some 32 acres for broad irrigation and 14 filter beds, 8 of which are 150 feet by 350 feet and the balance one-half that size. That portion of the disposal area which has been laid out in beds is stated to consist of fine soil 3 feet deep, below which is a layer of sand and gravel of unknown depth, admirably suited for filtration. The fine, deep soil contains a layer of rather poor, brownish-black material about 8 inches thick, below which is red loam sand, finely divided and nearly without grit. The sand and gravel farther down are very coarse, most of the sand being coarser than ordinary building sand.

In constructing the filter areas only about 12 inches of the top soil was removed, leaving about 2 feet of the fine material above the coarser subsoil. The filter beds have been underdrained with 6-inch tile placed 2½ feet below the surface at their upper end and 5 feet below at their lower ends. Inspecting chambers are placed at the junction of each under drain with the main drain. The main drain discharges into water carriers leading to a neighboring river.

Sewage was first discharged upon the original filter areas in September, 1893. It was then reported that very little effluent appeared in the underdrains, and that the discharge from them grew less and less until finally practically none appeared. The clear inference is that the effluent passed on down below the drain pipes and sank into the coarse material below.

Considerable trouble has ensued at Meriden, chiefly by reason, apparently, of neglect of the fundamental principles of sewage purification and utilization, not only as worked out in detail by the experiments of the Massachusetts State board of health, but as practiced successfully for many years abroad. The beds have not only been overdosed, but in their original preparation the exceedingly fine material above the subsoil was partially left instead of being fully removed, with the result that the filtration was not only very slow, but the filtering material was soon clogged. In 1895 all the beds were stripped of top soil and fine sand. Since that time the results have been much better.

So far as can be learned, no special attempt has yet been made to

grow crops upon the filter area, although the land utilized was selected by the designing engineer, Mr. Bassett, with special reference to such use. Possibly future reports from Meriden may indicate more satisfactory results. An attempt at sewage farming on a large scale at this disposal area would be watched with great interest by everybody. Markets for all kinds of produce are near at hand, and there seems to be no reason why, with proper management, a sewage farm here might not be very successful.[1]

Waterbury.—This town had a population in 1890 of 28,646. As we have seen on a previous page, the pollution of Naugatuck River by manufacturing wastes is very serious. It is understood that plans are now under way looking toward the purification of the sewage of Waterbury by land treatment.

NEW YORK.

Brewsters.—The so-called system of electrical treatment as used at Danbury, Connecticut, was also applied by the New York City department of public works for treating both sewage and water at Brewsters in the summer of 1893. So far as can be learned, the process has not been any more successful at Brewsters than at Danbury. In a paper read by Dr. Thomas M. Drown before the New England Water Works Association on March 14, 1894, it is shown that the so-called electrical purification is simply a process of disinfection by sodium chloride, in which electricity has nothing further to do with the process than that sodium hypochlorite is produced from salts naturally present in the sewage by electrolysis. It is probable that the cost of any treatment which includes the preparation of sodium hypochlorite by electrolysis is more expensive than it would be to buy this salt in the market and apply it by the ordinary methods of mixing used in chemical purification.

Brooklyn, Twenty-sixth ward.—Chemical-purification works have been recently constructed in the Twenty-sixth ward of the city of Brooklyn, in general accordance with the patented process of J. J. Powers. This process has also been carried out at Coney Island, Echota, Round Lake, White Plains, Sheepshead Bay, and other places in the State of New York. As originally operated, perchloride of iron was the only precipitant used, but in the more recent plans lime is also added and the sludge is further dosed with chlorine gas. Perchloride of iron costs about 3.5 cents a pound in New York. Chlorine is prepared from common salt, black oxide of manganese, and sulphuric acid. As to the cost of operating this system, the following approximate estimate of the daily expense at White Plains may be given:

[1] The works at Meriden were reported upon by Messrs. T. H. McKenzie, Simpson C. Heald, and Carroll P. Bassett. As to the views of each of these engineers, etc., see Eng. News, Vol. XXXIV, July 18, 1895, where an extended account of the works may be found.

Estimate of daily expense at chemical-purification works at White Plains, New York.

1 carboy of perchloride of iron	$4.75
1 barrel of lime	.75
Coal	.90
Engineer	2.25
Laborer and watchman, each, $1.50	3.00
Common salt, black oxide of manganese and sulphuric acid	.50
Oil and waste	.30
Miscellaneous	.50
Total	12.95

At the time this estimate was made, the average daily quantity of sewage treated was about 250,000 gallons. Assuming an average cost for treating this quantity of $12 instead of $12.95, we reach the figure of $48 per million gallons treated, which figure may, however, be expected to decrease somewhat with larger quantities of sewage treated. The figures show, however, that this is an exceedingly expensive process under any circumstances, as will be more readily realized when it is stated that the land processes, aside from yielding returns from the crops, do not ordinarily cost more than a few dollars per million gallons treated.

Chautauqua Assembly.—Chemical-precipitation works were constructed at the Chautauqua Assembly in 1893. This place has a summer population at times of several thousand. Measurements of the flow of sewage July 24, 1893, showed a total of 122,884 gallons in twenty-four hours.

According to an advertisement issued by the committee in charge of the Assembly grounds in October, 1892, the plans were required to embody a complete plant capable of sending out a clear and odorless effluent harmless to fish life, the object of the works being chiefly the maintenance of the cleanliness of the Chautauqua Lake beach in front of the Assembly grounds. The plans adopted were those of W. B. Landreth, and include the use of lime and sulphate of alumina as precipitants. The following analysis, made by Prof. Maurice Perkins, of Union College, in September, 1893, indicates the degree of purification obtained at this plant.

Analyses of water from chemical-precipitation works at Chautauqua Assembly.[1]

[Parts per 100,000.]

	Sewage.	Effluent.	Per cent removed.
Total solid residue	117.0	23.6	79.8
Mineral matter	59.2	14.4	75.7
Loss on ignition	57.8	9.2	84.1
Chlorine	6.0	6.0	0.0
Free ammonia	24.28	1.357	44.1
Albuminoid ammonia	2.068	.486	76.9

[1] Mr. Landreth has recently stated to the author that the results of this analysis have been fully verified by repeated analyses made each season since 1893.

If the results given in the foregoing are maintained permanently the Chautauqua Assembly sewage-disposal plant may be regarded as of a very high order.

In 1893, from July 1 to October 1 (ninety-two days), the cost of labor was: Superintendent and engineer, $255; helper, $131; total, $386, or at the rate of about $4.20 a day. The amount of chemicals used per diem is stated to average about as follows: Lime, 1 barrel; alumina sulphate, 30 to 40 pounds; copperas, 2 to 5 pounds. Fuel is estimated to cost about 30 cents a day. Taking labor at $4.20, fuel at 30 cents, and chemicals at $1.75, we reach a total of $6.25 a day. Assuming an average attendance of 4,000 people during the season, the daily cost per capita is found to be 0.156 cent, or at the rate of 57 cents per capita per year. Chemicals on the foregoing basis cost about 16.1 cents per capita per annum. Taking the actual flow of sewage as averaging about 125,000 gallons a day, we reach a cost per million gallons treated of $8.88 for lime, $7.76 for alum, and $1.28 for copperas, or a total of $17.92 per million gallons treated, which again indicates somewhat greater expense for chemical treatment than would be required for treating the same amount of sewage on land. Inasmuch, however, as the results were largely experimental in 1893, it is possible that later figures would show a marked reduction in cost. Chemical treatment will, however, even under the most favorable circumstances, cost more than land treatment, other conditions being, of course, assumed as equal.[1]

Far Rockaway.—Population in 1890, 2,288. Plans for sewerage and sewage disposal were approved by the New York State board of health in 1895; they include the collection of the sewage of the village at central points, from which it is to be pumped, by means of an electric motor and motor pumps, to a disposal field, where it will be purified by land treatment. It is understood that the work is at present under construction.

New Rochelle.—Population in 1890, 8,217; at present it is perhaps 11,000. A chemical purification plant, designed to treat eventually 750,000 gallons of sewage a day, was carried out in 1894 at an estimated cost of about $19,000. In addition to this sum, 2 acres of land purchased, right of way, legal expenses, etc., were estimated to cost about $4,380, or a total of about $23,380. Statements are lacking as to either the efficiency of the process or just the method of treatment pursued.[2]

Hemlock Lake.—The domestic water supply of the city of Rochester is obtained from Hemlock Lake, about 30 miles southerly from and at an elevation of 386 feet above the city. The works for bringing this supply to Rochester were constructed in 1874 and 1875, about which time the attention of the citizens of Rochester as well as those of the

[1] Refer to Eng. News, Vol. XXXI, February 1, 1894.

[2] Refer to Eng. News, Vol. XXXIII, February 28, 1895; and Eng. and Bldg. Record, Vol. XXXI, March 9, 1895.

surrounding cities and towns was attracted to the lake as a desirable point for summer residence. In 1892 there were in use about 120 cottages and several hotels and summer boarding houses, and the summer population about the margin of the lake, including transient visitors, was from 800 to 1,000 persons.

In order to care for the sewage and house wastes the city of Rochester constructed in 1886 a pail system by which the night soil and garbage from the cottages and hotels are collected and removed to the foot of the lake, where the material is deposited in narrow trenches in thin layers, and, after treating with lime, each layer is covered with about 6 inches of dry earth. This process is repeated daily until the trench is nearly filled, when the remainder is rounded up with earth and a new trench is started. The surface of the full trench is then cultivated and cropped, and after a suitable period the same land is again used. The trenches were originally made about 3 feet deep, but experience indicates much more rapid destruction of the organic matter near the surface than at the lower levels. It has been found that after a period of three years the same trench can be used again. The plant includes a building with convenient arrangements for washing the pails during the summer and for storing them in winter, as well as a flat-bottomed scow for transporting the sewage receptacles on the lake, and a tramway and pier, with a total length of 2,200 feet, by which they are transported from the lake to the place of treatment. The approximate cost of the plant to April 6, 1891, including surveys, building, scow, wagon road, tramway, carts, pails, and land, was about $10,000. The yearly cost of operation is from $1,500 to $1,700. In winter only a few of the dwellings are in use and the collections are made weekly by wagon.[1]

Bath, Soldiers' and Sailors' Home.—Mr. Power's patented process, described on page 62, is in use at this place, where the permanent population may be taken at from 1,200 to 1,500. Chemicals are stated to cost fully $2,000 a year. Including fuel, labor, and other expenses, the sewage purification costs about $3 per capita per annum. A good opportunity exists at this State institution to elevate the sewage by pumping onto porous lands owned by the State just back of the home, where it could be efficiently utilized in irrigation.

Batavia, State Institution for the Blind.—The average quantity of sewage of this institution is estimated at about 10,000 gallons a day, this quantity being based upon an average daily consumption of water of 50 gallons per capita for the 200 officers and inmates. Chemical-treatment works costing about $6,500 and an outlet sewer costing $6,000, or a total of $12,500, were constructed in 1890–91. No statements as to the efficiency of the process are at hand.

Vassar College.—Vassar College is situated near the town of Pough-

[1] Refer to Ann. Repts. Ex. Bd. City of Rochester, and Sewage Disposal in the United States. The city of Rochester is now (1899) purchasing a strip of land about Hemlock Lake, including all the cottages, and this collection system will accordingly soon be discontinued.

keepsie, a short distance back of the city, upon a small stream, which reaches the Hudson River by a roundabout course of something like 6 miles. For a number of years previous to 1895 the college sewage flowed to a series of covered tanks, where it underwent a rapid filtration through peat, gravel, and other substances. The effluent from this process, while considerably clarified, was still objected to as unfit to pass into a small outlet creek, the township health officer alleging that its discharge was injurious to riparian owners below.

After considerable discussion, in which various projects were suggested, a plan for disposal by intermittent filtration and broad irrigation was prepared and carried out by Messrs. Noyes and Hazen in the fall of 1895. Under this plan the sewage first passed into a screening chamber provided with a screen rack formed of iron bars $\frac{1}{4}$ by 2 inches in diameter, placed seven-eighths of an inch apart. The sewage enters the screening chamber parallel to the screen rack and not against it. The matter collected at the screen is taken out each day, and after draining on a platform is removed to the boiler house and burned. From the screening chamber the sewage flows to a reservoir of 44,000 gallons capacity, from which it was pumped to the disposal area, which consists of two filter beds with a total area of 1.03 acres exclusive of the embankment. The filtering material is a rather coarse sand with an effective size of grain of from 0.30 to 0.40 millimeter.

The level of the ground water was found to be about 15 feet below the prepared surface of the filter areas, and as there was a gully near by which afforded a free outlet for the ground water, underdraining was deemed unnecessary.

The filter beds provided are regarded as sufficient to receive the entire sewage of the college, but as there was a considerable area of sandy soil near by at a somewhat greater elevation, the force main was extended to a point commanding this area, so that during the growing season several acres of land can be utilized for broad irrigation. In this way the fundamental principle of effective sewage utilization has been recognized in these works, the sewage going to the land when necessary for the best results of agriculture and to the filter areas when not needed on crops, thus insuring an efficient filtration at all times without reference to cropping.

Complete records as to the quantity of sewage do not appear to have been kept, although during the months of February and March, 1896, the average daily quantity is stated as 56,000 gallons, the range being from 32,000 to 113,000 gallons. The sewers receive roof water and the higher quantities are stated as due to accessions from this source.

The total cost of the works as constructed, including the preliminary expense involved in considering the various projects proposed before the final adoption of the sewage-utilization project, is stated at $7,500, exclusive of the land.

Chemical examinations have been made of the water taken from the brook receiving the effluent, above the point where the effluent enters as well as below, with the result of showing that the stream below the effluent now carries no trace of sewage contamination. A great improvement in the condition of the stream is also shown by analyses made before and since the beginning of the filtration by Mrs. Ellen H. Richards, one of the trustees at Vassar College, and analyst of the Massachusetts State board of health. The examinations are to be continued for considerable length of time in order to gain information as to the final effect on the effluent and as to other questions of interest to those planning similar works. The enterprise of Vassar College in carrying out so thorough a system and also in causing systematic examinations to be made for the purpose of acquiring information for future guidance is highly commendable.[1]

PLANTS PROJECTED IN NEW YORK.

Albion.—Population in 1890, 4,586. Plans for sewage disposal by intermittent filtration were approved by the State board of health in 1890. The sewage will be delivered at the filtration fields by gravity, and the topographical conditions are such as to admit of utilization in agriculture by broad irrigation on porous, sandy lands.

Cobleskill.—Population in 1890, 1,822. Plans for sewage disposal by chemical purification were approved by the State board of health in 1893. No information is at hand as to whether or not land-purification processes have been considered.

Cortland.—Population in 1890, 8,590. Plans for purification of the sewage of the town by chemical treatment were approved by the State board of health in October, 1893. The plans also include possible filtration through land, should a high degree of purity be found necessary. It is proposed to use lime and sulphate of alumina as precipitants. The plans, as approved, include a tank area for from 9,000 to 10,000 people, with arrangements whereby the capacity can be increased as required. The report of the engineer does not state whether or not the locality would admit of land-purification processes.

Flatbush.—Under the health laws of the State of New York, the governor may, on presentation of evidence as to the existence of a nuisance, order the same to be abated under plans subject to the approval of the State board of health. In 1894 Governor Flower issued such an order with reference to the sewage of the village of Flatbush, on Long Island, which then grossly polluted Mill Creek. No information is at hand as to the action finally taken under this order.

Fort Plain.—Population in 1890, 2,864. This town is situated in the narrow portion of the Mohawk Valley at a place where little opportunity for land purification exists, except that the town incurs the expense of pumping. The cities of Rome, Little Falls, and Utica, on the Mohawk River above Fort Plain, discharge sewage into the river without treat-

[1] For an account of the Vassar College works, see the Engineering Record of June 27, 1896.

ment. Under these circumstances a chemical purification plant was approved by the State board of health in 1893.

Fonda.—This place, with a population in 1890 of 1,190, is also situated in the narrow valley of the Mohawk River below Fort Plain. For reasons similar to those stated in the case of Fort Plain a chemical-purification plant for this place has been approved by the State board of health.

Fulton.—Population in 1890, 4,214. This village is situated on the Oswego River, 12 miles from Lake Ontario. Chemical-purification works using lime and sulphate of alumina for precipitants, and estimated to cost $19,500, were approved by the State board of health in 1894. The water supply of the city of Oswego is taken from the Oswego River about 10 miles below. The engineer's report does not state whether land-purification processes are feasible or not.

Gowanda.—The present population of this place is stated at about 2,500. Sewage-disposal works by the process of sedimentation followed by upward filtration were presented to the State board of health in 1895. The details are too meager to give any certain indications as to the probable success of the process as specially applied at this place. The cost of the tanks is estimated at approximately $4,000, with a fixed charge of $800 per annum for maintenance.

Herkimer.—The township of Herkimer, which includes the village, had a population in 1890 of 4,666. The present population of the village is, however, stated at about 4,700. Plans for sewage-disposal works were approved by the State board of health in 1893. They include chemical precipitation applied substantially as at Fort Plain and other towns of the Mohawk Valley.

Holly.—Population in 1890, 1,381. Plans for sewage purification by intermittent filtration were approved by the State board of health in 1890. The topographical conditions are such as to permit the use of the sewage in broad irrigation.

Jamestown.—Population in 1890, 16,038. Sewage-disposal works have been projected, but whether land processes will be used is unknown.

Ilion.—Population in 1890, 4,057. Plans for chemical treatment by the use of lime and sulphate of alumina were approved by the State board of health in 1895. As at Fort Plain, Fonda, Herkimer, and other places in the lower Mohawk Valley, no information is given in the report as to the possibility of applying land purification. This universal omission must be considered extraordinary in view of the water supplies on the Hudson River at and about the mouth of the Mohawk and just below.

Lyons.—Population in 1890, 4,475. Plans for sewage disposal and sewerage were submitted to the State board of health for approval in the summer of 1897. They include purification of the sewage by irrigation and filtration.

Mount Vernon.—Population in 1890, 10,830. Plans for treating the sewage by J. J. Power's patented process were approved by the State board of health in 1893.

North Tarrytown.—Population in 1890, 3,179. Sewerage and sewage-disposal works for this place were approved by the State board of health in 1894. The purification is to be by chemical treatment. The details given in the published reports are exceedingly meager.

Oneida.—Population in 1890, 6,083. This village is situated in the Mohawk Valley above Utica. Plans for the purification of sewage by chemical treatment were approved by the State board of health in 1893.

Pelham Manor.—Plans for chemical treatment of the sewage of this place were adopted by the State board of health in 1894. From the meager details given in the reports it is inferred that Mr. Power's patented process is to be used.

Rochester.—Population in 1890, 133,896. General plans for treating the greater part of the sewage of that portion of Rochester lying east of the Genesee River, including at present a population of about 75,000 persons, were prepared in 1888, but have remained thus far in abeyance. The plans as prepared propose a partial chemical purification by lime treatment, with discharge of the effluent into the Genesee River. There is a fine opportunity to utilize the sewage of the east side at Rochester by broad irrigation on sandy soils in the neighboring town of Irondequoit, which are now largely devoted to growing vegetables for the Rochester market. In view of the successful experience on a similar soil at Gennevilliers, in France, as described in Water-Supply and Irrigation Paper No. 3, the author can not but think that if the city of Rochester were to finally construct a chemical-purification plant as proposed it would miss the great opportunity of its municipal life.

Williams Bridge.—Population in 1890, 1,685; estimated at present at about 5,000. Plans for chemical treatment of the sewage were approved by the State board of health in 1894. The details of the plans as given in the reports are very meager.

NEW JERSEY.

Atlantic City.—This place is a well-known seaside resort, which has many visitors in winter, but a much larger number in summer. Its population in June, 1890, was 13,055, against 5,477 in 1880. It is said that during the height of the summer season 150,000 people sometimes visit this place.

Atlantic City is one of the few places in the United States where the sewerage and sewage-disposal systems are owned and operated by a private company. The purification plant in use consists, in effect, of an elevated bed in which sand with hay below is used as a separating material and from which the effluent falls in small streams about 3 feet to gathering gutters leading to the effluent pipe. The results gained are extremely unsatisfactory. Indeed, with the large quantity treated

at the present time it is doubtful if any improvement is effected. The answer to a recent letter of inquiry refers to the Atlantic City sewage-purification works as a great farce.

East Orange.—The population of this place in 1890 was 13,282. Sewage-disposal works with chemical treatment supplemented by filtration through land were constructed in 1887 and 1888. The chemicals used are lime and sulphate of alumina. So far as known, no attempt to raise crops on the filter areas has ever been made. The works are now out of use, the sewage going to the Passaic River by way of the Newark sewers.

Essex Fells.—This place is an improved suburban-residence district, with a daily flow of sewage of about 20,000 gallons. Originally the purification was merely such as could be obtained by sedimentation in a tank, supplemented by the flow of the effluent through a mass of broken stone, and thence into gravel. Two filter areas capable of purifying double the present flow were constructed early in 1897.[1]

Freehold.—Population in 1890, 2,932. A disposal plant by broad irrigation was brought into use in 1893. For this purpose 16 acres of land were purchased, upon which the sewage is delivered by gravity. A portion of this has an unfavorable peaty soil with a surface of from 6 to 12 inches of bog iron ore. The remainder is greensand, marl, and clayey gravel. The cost of the land, including right of way, was $4,120, and with fencing and preparation, $6,207. Engineering and superintendence cost $1,944. The entire force of labor consists of one man at $300 per annum. The disposal area was seeded with Hungarian grass the first year, which sold standing for $45, but the hay is said to have molded after being housed. An attempt to cure this grass the second year is also said to have failed. Probably if Hungarian grass is the proper crop to raise on this area, ensilage would be the best way to preserve it.[2]

Lawrenceville School.—A system of subsurface irrigation was carried out at this school in 1883. Additions thereto, either by intermittent filtration or by broad irrigation, were proposed in 1893. As to whether the improvements have all been carried out there is no information at hand.[3]

Long Branch.—The winter population of this place does not exceed 7,000 or 8,000, although the population in summer is estimated at from 80,000 to 100,000. Like Atlantic City, this place has granted a franchise for sewerage works to a private company. Chemical-precipitation and mechanical-separation sewage-disposal works were constructed in 1886. Definite information as to results is lacking.[4]

Morris Plains Asylum.—Works for sewage disposal by sedimenta-

[1] Refer to Eng. and Bldg. Record, Vol. XXXVI, July 3, 1897.
[2] Refer to Seventeenth Ann. Rept. New Jersey St. Bd. of Health, 1893.
[3] Refer to Trans. Am. Soc. Civ. Eng., Vol. XVI, 1887; Eng. and Bldg. Record, Vol. XVI, 1886; and Sewage Disposal in the United States.
[4] Refer to Eleventh Ann. Rept. New Jersey St. Bd. of Health, 1887.

A.

B.

SEWAGE DISPOSAL AT PLAINFIELD, NEW JERSEY

A, Main carrier as seen from screen tank (before erection of building); *B*, Distributing channel in bed No. 1.

tion and subsurface irrigation were constructed at this State institution in 1887. The sewage is also dosed with a small quantity of sulphate of alumina. No information is at hand as to whether sewage irrigation could be profitably used.[1]

Plainfield.—The present population of Plainfield is about 13,000. It is chiefly a residence town, a very large portion of the residents being New York City business men. The construction of a water supply a few years ago has had the usual result of emphasizing the need of sewers, but no practical move was made in this direction until 1892. It was then resolved to construct a sewerage system with purification by intermittent filtration and broad irrigation. The construction of the works was begun in 1894 and completed in 1895. The land selected for sewage disposal lies at an elevation of from 50 to 70 feet above mean sea level and can be mostly reached with the sewage of the town without pumping. For one district, however, it is arranged in the future to drain to a pump well, from which the sewage will be raised by automatic electric pumps into a neighboring main, whence it can flow by gravity to the disposal works. The works at Plainfield are of further interest because of a trial there of cultivation of the filtration area. The result of such experiment with indian corn is well shown on Pl. I of Water-Supply and Irrigation Paper No. 3, and on Pl. V of this paper. The flow of sewage is stated at present to amount to from 11,000 to 13,000 gallons per hour at 11 a. m., gradually diminishing from that time to 5,000 gallons at about 4 p. m., and again increasing from 7 p. m. to 11,000 gallons per hour at 11 a. m., as stated. The total flow in twenty-four hours is stated as about 230,000 gallons. The works were constructed under the direction of A. J. Gavett.

Princeton College.—Sewage disposal by broad irrigation was carried out at Princeton several years ago. An average daily flow of sewage of from 7,000 to 10,000 gallons is purified on a sloping field of about 4 acres which has 6 inches of black soil resting upon a homogeneous clay subsoil. The entire area is drained to a depth of 4.5 feet with 2-inch tiles laid 30 feet apart. Sewage is applied from a line of troughs at the upper margin of the field, which are changed from place to place as necessary.[2]

Summit.—Population of the township in 1890, 3,502. Sewage purification by intermittent filtration was first operated in 1892. The disposal area consists of 26 acres of land, of which 10 acres have been laid out. The following bacteriological examination, made by Dr. Richard N. Connolly, bacteriologist to the Passaic River Commission, indicates defects of some sort in these works.

Sample of raw sewage taken December 31, 1896, showed bacilli coli communis very numerous, with a total number of bacteria per cubic centimeter of 1,112,250.

[1] Refer to Eleventh Ann. Rept. New Jersey St. Bd. of Health, 1887.
[2] Refer to Twentieth Ann. Rept. New Jersey St. Bd. Health, 1896.

A sample of the filtrate from the westerly outlet taken at the same time also showed bacilli coli communis very numerous, with a total number of bacteria per cubic centimeter of 1,098,900.

A sample of the filtrate from the northerly outlet, also taken at the same time, showed bacilli coli communis numerous, with a total number of bacteria per cubic centimeter of 645,440.[1]

Westfield.—This town had a population in 1897 of about 3,000. Sewerage and sewage-disposal works were carried out in 1895 and 1896. The method of disposal is by means of intermittent filtration and broad irrigation. For the former four level beds of about three-quarters of an acre each have been prepared on the highest part of the disposal field, which lies at an elevation of about 80 feet above tide water. The soil ranges from a fine sand to a coarse gravel. For the present 12 acres have been purchased, the portion not included in the filter beds to be used for broad irrigation. Thus far only one man is found necessary to take care of the sewage. The cost of the plant, including land, was $8,435.[2] F. A. Dunham was designing and constructing engineer.

PENNSYLVANIA.

Altoona.—Population in 1890, 30,337; in 1895 the population was estimated at 35,500. The town is located at the base of the Allegheny Mountains, between the elevations, 1,110 and 1,350 feet above tide, and near the head waters of the Juniata River. A sewage-disposal plant, constructed in 1896 and 1897, is designed to purify the sewage of a little less than one-half of the city, which originally drained southward toward Hollidaysburg, the county seat of Blair County, which is situated on the stream originally receiving the sewage a few miles down.

The pollution of the streams receiving the Altoona sewage has been a source of controversy for many years, and in 1882 suits were brought against the city for polluting springs on property about 11,400 feet southward from the city limit. This case was finally decided against the city, and claims of damages, interest, and costs to the amount of $6,555.36 were compromised in 1895 for $2,812.45.

Early in 1895 surveys for a sewage-disposal plant were made by Mr. Harvey Linton, city engineer. Messrs. Rudolph Hering and Allen Hazen were employed as consulting engineers. The details of the Altoona sewage-disposal operations are exceedingly interesting, but too extensive to be gone into here, and we may simply state that the filter beds have a capacity of about 750,000 gallons a day. The land purchased for sewage disposal amounts to nearly 96 acres and cost $12,000. Of this nearly 70 acres are available for sewage purification. The new works were first operated in June, 1897. It is intended to raise corn upon the filter areas.

The specifications for this work, as prepared mostly by Mr. Hazen,

[1] Refer to Eng. News, Vol. XXVIII, December 8, 1892, and Sewage Disposal in the United States.
[2] Refer to Twentieth Ann. Rept. New Jersey St. Bd. Health, 1896.

present some interesting features. The following is the clause covering grading and embankments:

The general object of this work is to divide up the land into a series of level plats surrounded by embankments, so that each can be separately flooded without disturbing the others, and to prevent the overflow of the land by the stream in time of flood.

. . . . . .

The land should be kept in as loose and porous condition as possible, and to that end all that part of the area to be filled shall be plowed 1 foot deep and left in loose condition before commencing to fill, and the elevations of the filling shall be carried to such additional elevation as may be directed by the engineer, to allow for subsequent settlement to bring all parts of the bed to the same ultimate elevation.

The dividing embankments shall be solidly constructed and rolled if necessary. The stone removed from the land may be largely placed in them if not otherwise required. The outside embankment as low as ordinary high water shall be paved with stones removed from the field in such exposed places as may be directed by the engineer, and the remainder of the slope and top carefully sodded with firm, healthy sods.

Land stones over 4 inches long are to be removed from the surface material as fast as the same is removed and are to be placed in the embankments or along the river to prevent washing, as will best serve the interests of the work, and as may be directed by the engineer.

After removing the stones the surface of the beds shall be carefully graded and smoothed and left in porous condition, free from compacting from wheels or hoofs, and ready for receiving sewage.[1]

Norristown, State Hospital for the Insane.—The total population of this institution is about 1,500, and the total daily consumption of water about 325,000 gallons, or 150 gallons per capita. A sewage-disposal plant, with purification by filtration and broad irrigation, was constructed in 1885. These works are said to have been specially successful.[2]

Reading.—Population in 1890, 58,661. The proprietary process of the Pennsylvania Sanitary Sewage Company was carried out in 1895. It is claimed that the works have sufficient capacity to purify 15,000,000 gallons of sewage a day. The following statement embodies the main points of these works:

The sewage falls by gravity into reservoirs 20 feet in diameter, with coke filters 12 inches deep, through which the sewage first passes in order to screen out the coarser suspended matter. The reservoirs are ventilated by special passages which surround the smoke flue and are expected to discharge foul odors at a height of about 100 feet.

The sewage is drawn from the reservoir into a suction chamber, from which it is pumped to filter beds on the river banks, about a mile from the pumping station. These beds are two-story structures of brick, stone, and iron, 250 by 50 feet, each story being subdivided into ten compartments, making a total of twenty compartments 25 by 50 feet. The filter beds are divided into upper and lower sections, in order to combine aeration with filtration. The filtering material of the upper section consists of fine sand 2 feet thick. After percolating through

[1] Proc. Eng. Club of Philadelphia, Vol. XIV, July–September, 1897.
[2] Refer to Colonel Waring's Sewerage and Land Drainage, 1889.

this the sewage falls 8 feet to a lower filter, which is formed of various grades and sizes of filtering material. Inlets are provided in which air is to be circulated in the coarser material of the lower section. The effluent water is discharged directly into the river.

The author can not but think that the proposition to purify 15,000,000 gallons of sewage a day by this plant must be intended as a joke.[1]

Wayne.—This place is a suburban village with a population in 1890 of 997. It has grown rapidly, and at present the population is much greater. There are no manufactories. Sewage disposal by surface irrigation was carried out in 1891. The disposal area includes 11 acres of sidehill land, with creek flowing through the middle. A portion of the land is timbered, as shown by fig. 2 in Water-Supply and Irrigation Paper No. 3 and by Pl. VII in this paper.

The sewage flows by gravity to the pumping station, whence it is forced to distribution wells on adjacent highlands, from which it flows down the sidehill through heaps of broken stone. At various places below cinder banks are formed. A very efficient filtration is said to be obtained by this process in course of a few hundred feet below. In 1892 the average daily quantity of sewage was established at about 200,000 gallons. During that year five crops of grass were raised on the irrigated land.[2] The effluent water is discharged into the river.

WEST VIRGINIA.

Weston, State Insane Hospital.—Plans for sewage disposal by chemical precipitation, supplemented by broad irrigation, on about 27 acres of land on which it was intended to grow crops were prepared in 1891. In view of the sewage farming offering an opportunity for employing a considerable number of harmless insane in light outdoor labor, it was believed that this project was an especially feasible one. Thus far, however, the West Virginia legislature has not appropriated the $40,000 necessary in order to carry out the project in full detail.[3]

TEXAS.

Paris.—Population in 1890, 8,254. This town is finely located in northwestern Texas, about 14 miles from Red River, at an elevation of 588 feet above tide water.

Sewers were constructed in 1894, discharging into a small stream known as Bankers Creek. Soon after constructing a main sewer, farmers on this creek below the outfall brought suits for damages aggregating $15,000. Trial of one of them resulted in a verdict against the city of $900.

The suits had the effect of forcing attention to some other means of sewage disposal, and in the early part of 1897 a system of disposal

[1] Eng. and Bldg. Record, Vol. XXXI, May 4, 1895.

[2] Refer to the Am. Arch., July 2, 1892; Eng. News, Vol. XXVIII, November 3, 1892; and Sewage Disposal in the United States.

[3] Refer to Jour. of W. Va. House of Delegates, February 18, 1891.

by intermittent filtration was begun. For this purpose the city purchased 10 acres of land for $750, of which 5½ acres have been laid out. The cost of constructing 5½ acres of filters is given at $3,730. The present daily flow of sewage is from 35,000 to 40,000 gallons. The sewage-disposal areas are cared for by one man, who is paid at the rate of $420 a year. It is proposed to crop with alfalfa in 1898.[1]

San Antonio.—Population in 1890, 36,673. The city purchased 530 acres of land in 1895, with the expectation of establishing a sewage farm. Information is not at hand as to the present state of the enterprise.

Temple.—Population in 1890, 4,047. It is understood that this place has recently granted a franchise to a private company to construct and operate sewerage and sewage-disposal works.

OHIO.

Alliance.—Population in 1890, 6,707. A chemical-purification plant estimated to cost $18,400 has either been recently constructed or is about to be constructed at this place. As to just the present state of the project, no information is at hand.

Canton.—Population in 1890, 26,189; present population estimated at about 35,000. The outfall sewer originally discharged raw sewage into the main branch of the Nimishillen Creek. Complaints were made several years ago by the owners of land abutting on the creek below the outlet of the sewer, thus bringing the question of sewage purification before the city authorities, who acquired 28 acres of land at and about the sewer outfall for the purpose of providing some method of purification. Chemical treatment was finally decided upon as adequate to the requirements, although the relative cost of chemical purification versus land treatment does not appear to have been gone into. The works were constructed under the supervision of L. E. Chapin, city engineer.

The plant was first started in May, 1893, since which time all the sewage of the city has been treated. The following analyses, made by Dr. Curtis C. Howard, in which the results are stated in parts per 100,000, indicate the degree of purification effected. No. 1 is the average of 24 samples of the raw sewage, and No. 2 the average of 24 samples of effluent taken at the same time as No. 1.

Analyses of raw sewage and of effluent, at Canton, Ohio.

[Parts per 100,000.]

	No. 1.	No. 2.
Free ammonia	0.894	0.676
Albuminoid ammonia	.326	.112
Chlorine	2.14	2.05
Total solids	49.3	41

[1] Refer to Eng. News, Vol. XXXVIII, August 12, 1897.

The cost of the sewage-disposal plant at Canton to March 15, 1897, is as follows:

Land	$4,100.00
Construction	27,215.23
Material	14.70
Total	31,329.93

The cost of maintaining the works in 1896 was as follows:

Labor	$1,630.00
Coal	356.76
Lime	739.63
Alum	502.75
Oil and waste	33.01
Filter sacks	46.68
General repairs	61.91
Miscellaneous	44.50
New smokestack	137.00
Total for year	[1] 3,552.23

Fostoria.—The population in 1890 was 7,070. Plans for sewage disposal by land purification were prepared in 1895. As to whether they have yet been carried out no information is at hand. The conditions are such as to require pumping to the disposal field. Cost of disposal works is estimated as follows:

24½ acres of land, at $150	$3,675.00
Preparation for beds, including underdrainage, grading, force main, main carrier, and effluent drain	6,425.00
Reservoir, sludge and pump well, necessary buildings, boiler, and pumps	14,920.00
Total	25,020.00

Running expenses with coal as fuel are estimated at about $1,843 per year, without taking into account the profit to be realized from the sale of produce raised on the filter areas.[2]

Oberlin.—This place, which is the site of Oberlin College, had a population in 1890 of 4,376. A sewerage system, with disposal by broad irrigation, was constructed in 1893. The irrigation field includes 15 acres, purchased at a cost of $1,500. In 1894 the daily flow of sewage varied from 35,000 to 40,000 gallons. In addition to broad irrigation, 9 filter beds have also been prepared, of which 3 are devoted to raising woodland rye grass, 3 to alfalfa, and 3 to corn and garden vegetables.

The soil, which consists of yellow clay underlain at a few feet by stiff blue clay, is not specially favorable for sewage disposal. As to the best methods of treating such a soil, reference may be made to a description of the sewage farm at Wimbledon, England, in Water-Supply and Irrigation Paper No. 3. The Oberlin sewage farm is also especially interesting because of the small amount spent in preparation.

[1] Refer to Canton Municipal Reports and Tenth Ann. Rept. Ohio St. Bd. Health, 1895.
[2] Refer to Tenth Ann. Rept. Ohio St. Bd. Health, 1895.

The following are the figures:

6,000 feet of agricultural tile	$256
Tool house	55
Grading and incidentals	166
Small pump and tank	42
Land	1,500
Total	2,019

Some reports as to a nuisance at the Oberlin sewage farm having gained circulation, a committee of the Ohio State board of health inspected it in July, 1895. In their report the committee say that no just cause exists for complaint in respect to the Oberlin sewage farm.[1]

Sewage disposal plants are also reported as projected at Bowling Green, Cambridge, Chillicothe, Columbus, Glenville, Greenville, and Mansfield, Ohio.

MICHIGAN.

Wayne County Poor Farm.—A chemical precipitation plant, costing about $10,000, was first operated at this institution in 1896. Cost of operation, including chemicals and attendance, is estimated at about 80 cents per capita per annum for a population of 800.[2]

St. Johns.—Population in 1890, 3,127. A land-purification project has been proposed.

ILLINOIS.

Pullman.[3]—This farm was laid out in 1880 and 1881 by the Pullman Palace Car Company as a means of purifying the sewage of the model town of Pullman, which is about 14 miles south of Chicago and at present is included within the limits of that city. The population in 1893 was 11,000. The only body of water in the vicinity which could possibly receive crude or raw sewage is Lake Calumet, a lake about 3 miles long, 1½ miles wide, and from 1 to 8 feet deep. The extreme shallowness of this lake, as well as the absence of current, renders it very undesirable as a place for disposing of crude sewage, and the country about Pullman is so flat that it was necessary to pump the sewage to the area selected for farming purposes. The area originally selected comprises about 1,500 acres, though thus far only a small part of this tract has been used. In 1892, with an average daily flow of sewage of about 1,850,000 gallons in twenty-four hours, the land in actual use did not exceed 140 acres.

This farm is of special interest in the present connection, because its original design recognized the principle of having filter areas on which any surplus sewage not needed for the best results in irrigation could be purified. It should not be overlooked that reports have frequently come from Pullman that the sewage was often allowed to flow into

[1] Refer to Ninth Ann. Rept. Ohio St. Bd. Health, 1894 and 1895.

[2] Refer to Eng. and Bldg. Record, Vol. XXXIV, July 11, 1896.

[3] The use of this farm for sewage disposal has recently been discontinued.

Lake Calumet in nearly its natural condition. On this point it may be remarked that the projectors have probably felt that little harm was done to anybody so long as no nuisance was created in the lake or along its margins. The fact that a portion of the ice supply of Chicago was taken from Lake Calumet during the winter has been considered with indifference. Owing, therefore, to either inefficient or indifferent management, the Pullman farm can not be referred to as a specially successful example of sewage purification, although, from the statements made, the utilization has justified in a commercial way the expectations of its projectors. The farm is stated to have yielded in some years a net profit of from 8 to 10 per cent. The designing engineer, Benezette Williams, of Chicago, is entitled to the credit of having made his design sixteen years ago in line with what is universally considered to be the best practice of the present day.

The soil at Pullman is the ordinary prairie black alluvium, about 1 foot in depth, and mostly underlain by a clay subsoil. It is therefore not the most favorable for utilizing a large volume of sewage on a small area. From what has been learned in regard to this farm, it is the author's opinion that a considerably larger area should be used. With this improvement, as well as some additions to the filter area in order to afford sufficient relief in wet weather, it is believed that sewage farming can be made very successful at Pullman, from the points of view of both purification and utilization.

The underdrains are of common agricultural tile, laid about 40 feet apart to an average depth of about 4½ feet. The most satisfactory crops are cabbage, cauliflower, celery, and other vegetables common to market gardening. For some reason the raising of potatoes has not been successful on this farm. Italian rye grass is also reported as unsuited to the conditions, but whether the difficulty is due to climate or soil, or both, is unknown. Very little live stock is kept, because market gardening for the Chicago market is more profitable. During the growing season about forty laborers are employed at the current rates of common labor in the vicinity of Chicago.

The distribution of sewage at Pullman is effected by the pipe-and-hydrant system. For this purpose vitrified tile pipes, tested by water pressure before laying, have been successfully used.

The foregoing short account of the Pullman sewage farm is given here, not because it is an example of the best work in sewage utilization, but because it was the first large sewage farm in the United States, and because, further, it was designed in accordance with the now universally recognized principle of intermittent filtration relief areas. In view of the large experience gained elsewhere, failure to purify the sewage efficiently at all times must, as has already been pointed out, be attributed to the management rather than to the method. Under this head it may be remarked that thus far the American farms, generally speaking, have not realized their full agricultural capacity

by reason of defects in management. We need to develop here, as there have been developed abroad, a class of sewage-farm managers who, having made a specialty of this method of farming, shall be not only informed as to details but qualified to meet emergencies.

As regards sewage-purification works owned and operated by towns, it may be said that the entire separation of the management of the works from local politics will be the first necessary step toward increased efficiency.

World's Fair.—The sewage of the World's Columbian Exposition, in 1893, was purified by mechanical precipitation before discharged into Lake Michigan. The plant assigned for this purpose embodied the method of vertical tanks, an illustration of which may be found at page 556 of Sewage Disposal in the United States.[1]

This plant was placed in charge of Mr. Allen Hazen, who made extensive studies as to its efficiency. The daily quantity of sewage treated varied from about 6 million to 9 million gallons. The total cost of treatment per million gallons was $38.09. The works cost about $55,000, of which $20,000 was for the building.

The cost of the chief precipitant used varied from $20.40 to $47 per ton. Mr. Hazen's results are given in considerable detail, but can not be further gone into here. On the whole his report is adverse to the efficiency of the process.[2]

WISCONSIN.

Menominee Valley.—The sewage-disposal plants in Menominee Valley have been described on page 24, in connection with the discussion of purification of manufacturing wastes. They include Schmidt's Curled Hair Works, McBride's Sanitarium, the National Soldiers' Home, the public institutions of Milwaukee County, and the Miller Brewing Company.[3]

MINNESOTA.

Rochester Hospital for the Insane.—Sewage disposal by chemical precipitation supplemented by intermittent filtration was first operated at this State institution in 1890. The population of the hospital is stated at about 1,050 persons, with a total sewage flow of 60,000 gallons a day. The sewage first flows to tanks of sufficient capacity to handle 75,000 gallons a day, from which, after treatment with chemicals, the effluent is pumped to a filtration area with about 16 inches of surface loam, below which is sand and gravel. This area is underdrained with 3-inch tile laid in lines about 25 feet apart. In spite of the low winter temperature of Minnesota, it is stated that no trouble has been experienced in securing sufficient winter purification. The sewage probably

[1] Additional illustrations of this plant are given in Eng. News, Vol. XX, August 3, 1893.

[2] The full results of Mr. Hazen's studies of the World's Columbian Exposition sewage-disposal plant may be found in the Twenty-fifth Ann. Rept. Mass St. Bd. Health, 1893.

[3] Refer to Eng. News, Vol. XXXIII, June 13, 1895, and Sixteenth Rept. Wis. St. Bd. Health, 1895–96.

reaches the precipitation tank in cold weather with a temperature of about 45° F.[1]

NEBRASKA.

Hastings.—Population in 1890, 13,584. Stated present population, 15,000 to 18,000. A sewage farm of about 70 acres was carried out in 1891 or 1892. The soil of this farm is open and porous, and, so far as known, has not been underdrained. No information is at hand as to the success experienced in cropping.[2]

COLORADO.

Colorado Springs.—Population in 1890, 11,140. A sewerage system was carried out in 1888 and a sewage farm in 1889. Soon after opening the sewage works a ranchman living 2 miles below the outfall, which is into a small stream with a normal flow of about 50 cubic feet per second and at times with no flow at all, instituted injunction proceedings, claiming that his well was so polluted as to render the water unfit for drinking, and that the water in his irrigating ditch, of which the head gate is about three-quarters of a mile below the sewer outfall, was so foul that stock would not drink it. The matter was arbitrated and the suit withdrawn, the city paying all costs of proceedings and agreeing to divert the sewage and utilize it for irrigation.

A contract was then made between the city and the owner of a tract of about 35 acres of land upon which the sewage could be conveniently diverted by gravity, the city agreeing to pay $300 annually for five years, and the owner on his part agreeing to use the sewage for irrigation purposes in such manner as he deemed best, provided, however, that the sewage be prevented from flowing directly into the creek, and provided further, that if the method of irrigation was not satisfactory to parties on the stream below, the city should take possession of the land and use such methods as it thought best. At the expiration of the contract the city was to have the option of buying the land at a stipulated price. Whether or not this has been done is not known. The irrigation, however, is said to have been very successful. In 1892 sewage was used on 25 acres—15 acres in meadow and alfalfa and 10 acres in vegetables. The crops produced have been very large, and owing to close proximity to market the farm is said to be a paying investment.

As illustrating the demand for water in this section, it is stated that farmers several miles below the sewer outfall, seeing the sewage farm well supplied with water at times when their farms were suffering from shortage, have threatened to enjoin the city from using the sewage for this purpose, and thus compelling it to turn the sewage into the stream for their benefit.[3]

Leadville.—Population in 1890, 10,634. The sewerage system of this

[1] Refer to Sixth Biennial Rept. of Trustees, 1890, Eng. and Bldg. Recd., Vol. XXIII, and Sewage Disposal in the United States.

[2] Refer to Eng. News, Vol. XXIX, March 9, 1893, and Sewage Disposal in the United States.

[3] Refer to Eng. News, Vol. XXIX, February 23, 1893, and Sewage Disposal in the United States.

A

B.

SEWAGE IRRIGATION AT SALT LAKE CITY, UTAH.

A, Main ditch, outlet gate, and field of corn; *B*, Lateral ditch and method of irrigating corn.

place was built in 1886 by the Leadville Sewerage Company. The original sewage-disposal works as constructed by this company included a sand and gravel filter about 6 or 7 feet deep, with a surface area of 24 square feet. Whether this extensive sewage-disposal plant is still in use is not known.

Trinidad.—Population in 1890, 5,523. A sewerage system was first operated in 1892. Sewage is first received in a settling tank 50 feet long, 5 feet wide, and 4 feet deep, from which it flows upon land. To the end of 1892 about $1,200 had been expended in preparing the irrigation area to receive sewage. Blue grass was originally proposed as a crop on the farm, because it was supposed that this grass would stand more frequent irrigation than any other crop. A private party owns the irrigation area, on which the city delivers the sewage and pays $500 a year to the owner.

MONTANA.

Helena.—The population in 1890 was 13,134. A sewerage system was first operated in 1889. At this place the sewage is utilized only in the growing season. During times when the ground is so frozen that there is no absorption, sewage flows in natural channels upon the surface. The lower end of the outfall sewer connects directly with the distributing ditches of the farm, which includes 40 acres of land, purchased for $6,100. It is leased at an annual rental of $200. Crops raised are vegetables and nursery stock.

UTAH.

Salt Lake City.—Population in 1890, 44,843. A sewage farm was carried out at this place under the direction of F. C. Kelsey, city engineer, in 1895 and 1896. The daily flow of sewage is stated at 4,000,000 gallons. In addition storm water to the amount of 15,000,000 gallons per day may be expected at different times. The land acquired by the city amounts to 183 acres, of which 80 acres have been plowed and are under cultivation in 1897. It fronts on the Jordan River and the main ditch is extended to the stream, so that when the outfall sewer is running full the flow can be diverted directly to the river without passing over the land. Settling basins to the extent of 30 acres have been prepared.

Sewage was first delivered on the farm on July 11, 1896. No crops were planted that year except 5 acres of corn for fodder. It is intended to improve the farm by erecting buildings, planting shade trees along the highways, and an orchard of 6 acres, which is too high for irrigation, but thus far the money has not been furnished for these improvements.

The results of this extensive sewage irrigation at Salt Lake City will be looked for with interest, the more especially as, when the sewage farm was first proposed, it was thought that neighboring farmers would be willing to take the sewage for irrigation, because all land at Salt Lake City necessarily requires irrigation. The farmers, however, refused to take it, mainly, it is said, from ignorance, thinking it would damage the

crops, clog the ground, and be otherwise injurious. It was for this reason that the city embarked in sewage farming.[1]

The total cost of the sewage farm to January 1, 1897, was: Land, $14,763.45; plowing, $273.42; preparation of surface, etc., $3,452.64; total, $18,489.51.

The total cost of handling the sewage for the last six months of 1896 was $683.36. Assuming an average of 4,000,000 gallons a day, this would be at the rate of about 93 cents per million gallons handled for the six-months period. Probably when the sewage farm is in full operation the cost will be greater, but it will be met by sale of crops.

ARIZONA.

Phœnix.—Population in 1890, 3,152. The waterworks, sewerage, and sewage disposal at this place are all owned by the Arizona Water Works and Sewage Company. According to the information at hand, 160 acres of land have been provided for a sewage farm, on which sewage is largely used for irrigating garden truck by Chinese gardeners. The results are understood to be satisfactory. A view of an irrigated field will be found in Pl. VII.

CALIFORNIA.

Fresno.—Population in 1890, 10,818. Sewers were constructed in 1889. In 1890 a contract was made with Alexander McBean, of Oakland, to take the sewage and purify it by irrigation, the city paying therefor $5,000 per year. Mr. McBean purchased 80 acres of land at the outfall, and during the first year the sewage ran upon it without special attention or care, except when some neighbor saw fit to take it for irrigation. The second year distribution ditches were constructed and the land leased to Chinese gardeners for vegetable gardens and vineyards. The land is now all under cultivation with the various kinds of vegetables commonly in the market, such as potatoes, yams, parsnips, lettuce, celery, beans, peas, and corn. Statements as to the amount of sewage are lacking.[2]

Los Angeles.—Sewage irrigation at Los Angeles is of considerable interest, because the most extensive sewage farming by private owners in the United States is practiced there. The population, according to the census of 1890, was 50,395. In 1894 a conservative estimate placed it at 70,000.

Los Angeles is built upon both sides of a torrential stream, Los Angeles River, at a point about 20 miles from its mouth, and at a distance of about 12 miles from the Pacific Ocean. Sewage irrigation here was originally carried on by a private company, which took the sewage as delivered from the main outfall sewer and conveyed it by ditches to an area on which it was utilized in agriculture as required on various small tracts, the surplus being allowed to flow away into

[1] Refer to the Salt Lake City Municipal Rept. for 1896, and Eng. News, Vol. XXXVII, March 13, 1897.
[2] Refer to Sewage Disposal in the United States.

A. SEWAGE IRRIGATION AT PHŒNIX, ARIZONA.

B. SIDEHILL IRRIGATION AT WAYNE, PENNSYLVANIA

the stream unpurified. In the course of time the area originally irrigated became city property, and a large portion of it having been sold for residence sites, many of the landowners objected to sewage irrigation and obtained injunctions restraining its use in this way. According to the statements made there was at one time considerable nuisance from the sewage irrigation. The ditches were not kept clean, and under the hot sun of southern California they gave forth a strong odor. The objection was also made that sewage irrigation was detrimental to the health of the community, but so far as can be learned no facts have ever been produced to support this objection.

The sewage has been mostly used in growing vegetables for the Los Angeles market, and, according to the statements made, its commercial value for such purpose has been considerable.

As the result of several years' discussion the city of Los Angeles has recently constructed a main outfall sewer leading to the Pacific Ocean, along the line of which numerous valves have been placed, as is done at other places where successful sewage irrigation has been practiced, not only for drawing off the sewage for use in agriculture, but for restricting its use to such times as it may be needed.

The soil for a considerable portion of the distance along the main sewer is light and sandy and especially adapted to successful sewage purification, and it is believed that a considerable use of sewage for this purpose will be developed soon.

In 1895 and 1896 a total area of about 1,550 acres was irrigated along the line of the new outfall sewer, the amount of sewage used upon this acreage varying from 8 to 10 cubic feet per second. An area of 800 acres near the city is mainly devoted to raising vegetables. The balance was planted in corn and other fall crops, among which were about 100 acres in potatoes and cabbage. According to the reports of the city engineer for the years 1895 and 1896, the following revenue was realized from the sale of sewage:

Revenue realized from the sale of sewage at Los Angeles, California, in 1895 and 1896.

1895.		
Receipts from the sale of sewage		$3,278.00
Maintenance:		
Salary of superintendent	$1,000.00	
Assistance and labor	625.47	
Repairs, etc	512.50	
		2,137.97
Net revenue		1,140.03
1896.		
Receipts from sale of sewage		$4,009.50
Maintenance:		
Salary of superintendent	$1,200.00	
Assistance and labor	1,675.40	
Repairs, etc	184.80	
		3,060.20
Net revenue		949.30

In 1883 the city of Los Angeles entered into contract with the South Side Irrigation Company, obligating itself to give to said company all the sewage flowing through the San Pedro street sewer, amounting to about 3.58 cubic feet per second. In October, 1895, a second contract was made with the same company, whereby the city agreed to deliver until the expiration of the former contract an additional quantity of 2.39 cubic feet per second, or a total until 1903 of a little less than 6 cubic feet per second. In consideration of the last amount the company has laid a 24-inch cement pipe, 6,000 feet of which lies within the city limits and which will become the property of the city in 1903. The company also has the right to use an additional quantity of sewage by paying the prevailing price for it, which during the height of the irrigation season, in April and May, has been placed at $8 per twenty-four hours for 2 cubic feet per second. The rate is also made $5 for a day run of twelve hours and $3 for a night run, to suit the convenience of the irrigators.

The sewage now controlled by the South Side Irrigation Company is mainly used for irrigating about 2,200 acres of land devoted to vegetable gardening. The sewage is distributed throughout the land irrigated by ordinary open-earth ditches. This land now pays an annual rental of $12 per acre for river-water irrigation and $18 per acre for sewage irrigation, or $6 per acre in favor of the sewage.

On sandy soil with good subdrainage the South-Side Irrigation Company now irrigate successfully during the whole year. Experience has shown that when not actually needing the sewage for irrigation it is better to flood the land than to permit the sewage to go to waste.[1]

Pasadena.—Population in 1890, 4,882. Sewers were constructed from 1887 to 1891, and a city sewage farm was brought into operation in 1893. Its soil is a light sandy loam, with good natural drainage, and includes at the present time an area of 800 acres. The flow of sewage is estimated at about 3 cubic feet per second. According to statements of Mr. Burr Bassell, of the 300 acres actually owned by the city, 140 are used for raising grain and have never been irrigated. Sewage has been used upon the remaining cultivated area as follows: Walnut orchard (4 years old), 60 acres; alfalfa, 25 acres; corn, 25 acres; vege-

[1] In a paper by Mr. Burr Bassell, deputy city engineer of Los Angeles, on the Operation of the Los Angeles outfall sewer and sewage irrigation, which appeared in the Journal of the Association of Engineering Societies for August, 1897, many additional interesting details may be found. In the discussion of Mr. Burr Bassell's paper, James D. Schuyler, a leading California irrigation engineer, pointed out that, in view of the conspicuous success achieved in sewage farming abroad, the policy of constructing an outfall sewer to the ocean must be regarded as questionable, particularly in southern California, where the soil and climatic conditions are all extremely favorable for successful sewage farming. Mr. Schuyler expressed the hope that in the future growth of Los Angeles, when the capacity of the present outfall has been reached, extension of the system would be made in the line of utilization by irrigation and the establishment of a city sewage farm rather than in the duplication of the present sewer to the ocean. Mr. Schuyler gave a large amount of valuable information as to the comparative cost of river water and sewage irrigation in the vicinity of Los Angeles.

In addition to Mr. Bassell's paper, refer to Report of a board of engineers upon the disposal of the sewage of Los Angeles, etc., 1889, Eng. News, Vol. XXIX, February 23, 1893, and Sewage Disposal in the United States.

tables, potatoes, etc., 50 acres. The farm is self-sustaining, cost for maintenance and revenue being each about $2,500 per annum.

The experience at Los Angeles and Pasadena seems to be conclusive that there is no valid objection to the use of sewage for the irrigation and growth of all kinds of agricultural products. It is apparently a question merely of proper application. As showing the immense advantage of sewage disposal in the vicinity of Pasadena, it may be mentioned that bare land is worth at least $100 an acre without water, while watered land is held at about $600 an acre. The Pasadena sewage farm originally cost $125 an acre, or a total, including some extra expenses, of about $40,000.[1]

Redding.—Population in 1890, 1,821. A separate sewerage system was built by the town in 1889. Bassett & Rouhey, of Sacramento, the contractors for the sewage work, entered into an agreement to dispose of the sewage for forty years. For this purpose they purchased a tract of about 100 acres of land and prepared a portion of it for the utilization of sewage by irrigation. The area selected is comparatively level, with the soil a sandy and gravelly loam 4 to 6 feet deep, underlain by gravel. The sewage is applied directly to the land, either by running in furrows between rows or by spreading over the surface, according to the special requirements of each crop. The chief crops raised are corn, asparagus, potatoes, turnips, beets, and other garden truck. It has also been used for orchards and nursery stock. When used in this manner the trees were irrigated between the rows.[2]

San Luis Obispo.—Population in 1890, 2,995. Plans for sewage disposal by broad irrigation and intermittent filtration were prepared about 1888. No information is at hand as to whether or not they have been carried out.[3]

Santa Rosa.—Population in 1890, 5,220. Complaints of the pollution of the creek into which the sewage of the town was originally discharged, followed by a lawsuit, led to the purchase by the city of 18 or 19 acres of land on which the sewage has been purified since about 1889. The farm is leased to tenants, who take care of the sewage as rental, using it for gardening purposes.

Stockton.—Population in 1890, 14,224. The sewage of this place is stated to be used for irrigating purposes, but to what extent is not known.

DOMINION OF CANADA.

Berlin.—Berlin is the county seat of Waterloo County, and according to the census of 1891 had a population of 7,425. The chief industries of the town are manufacturing establishments, among which are included a large tannery and a glue factory. A public water supply

[1] Refer to Burr Bassell's paper in Jour. of Assoc. of Eng. Socs., Vol. XIX, August, 1897; and to Sewage Disposal in the United States.

[2] Refer to Sewage Disposal in the United States.

[3] Refer to Colonel Waring's Sewerage and Land Drainage, 1889.

was built in 1888. Construction of sewers began in 1892, and in March, 1893, the actual quantity of sewage was about 50,000 gallons per day, diluted by some 75,000 gallons of subsoil water, making a total of 125,000 gallons in all. A sewage farm was completed in the fall of 1892 and first brought into use in 1893. In January, 1893, the temperature of the sewage as it arrived at the farm was found to be 48° F. The farm is located a mile south of the closely built-up section of the town. A stream, with a summer flow of about 200 cubic feet per minute, passes through the farm and receives the effluent.

The field purchased by the town for sewage-disposal purposes has an area of 20 acres, about an acre of which is included in the stream. The total area aside from the stream can easily be used for sewage farming by slight grading, as the greatest elevation is only 3 feet above the end of the outfall sewer. The surface soil is loam or sand, and the subsoil is of gravelly clay.

The designing engineer recommended that Italian rye grass be raised on the two north divisions of the farm, and on the remainder mangolds and other root crops, onions, oats, and clover. On the lowlands bordering the stream it is proposed to raise osiers, they having been raised with profit in Brantford, where dependence is had upon the freshets of the Grand River for irrigation. It is stated that the farm is suitably arranged for every known system of irrigation and every variety of crops. This farm is interesting from the fact that, as at the Croyden-Beddington farm, no settling tank has been provided, preference being given to the application of the solid matter directly to the land, where it can be dug in or raked off, as may be found most desirable. When in the course of time the amount of sewage has increased so that it exceeds the capacity of the farm for disposal by broad irrigation, it is proposed to construct filter areas at the south end, where gravel may be obtained within reasonable distance. The 20 acres purchased cost $2,000, and the cost of grading and underdraining the 7 acres already prepared was about $3,000, the underdraining and grading having cost at this rate a little over $400 per acre.

The results of cropping at Berlin are stated to have been substantially as follows: In 1894, 2,000 cabbage plants were set on about one-half an acre of land, of which 1,500 grew to marketable heads and were sold at the usual market price of 3 cents each. The cabbages were irrigated regularly and grew well. No attempt was made to hoe around them or hill them up, the surface of the ground being left entirely smooth.

The cultivation of Italian rye grass at Berlin does not seem to have been successful. The rye-grass seed was sown broadcast and soon came up, covering the ground with a mass of roots which are stated to have very much retarded the absorption of sewage. This experiment was made on a filter bed in a manner quite different from the ordinary practice of rye-grass cropping abroad. A chief difficulty of this trial

appears to have been an improper preparation of the land, depressions being left into which the sewage settled and which soon became foul. Abroad, on the contrary, this crop is not raised on beds at all, but on land so prepared as to avoid pondage of the sewage; besides this, the amount of sewage applied is regulated to the necessities of the crop and to the quality of the land, whereas at Berlin, so far as can be learned, the sewage application was made without special refefence to the conditions. Under these circumstances the failure at Berlin can apparently have no other significance than to illustrate an erroneous method of procedure.

In 1895 a large area was devoted to cabbage, but by reason of a late frost many of the plants were killed. Later the cabbages were reset and the seeds of onions, carrots, mangolds, corn, and beans were planted. These crops are stated to have all done well except the corn and beans. The following is a detailed statement of the sale of produce from the Berlin farm in 1895, as compiled from the proceedings of the committee of the town council in charge of the farm:

August, 1,217 heads cabbage, at 2½ cents	$30
September, 1,771 heads cabbage, at 2½ cents	44
October, 2,272 heads cabbage, at 2½ cents	57
October, 134 bushels carrots, at 15 cents	20
October, 648 bushels carrots, at 15 cents	97
Corn (failure)	7
Pease (not irrigated to any extent)	15
November, 1,350 heads cabbage, at 2½ cents	34
Total	304

In addition to the foregoing, 150 kegs of sauerkraut, of 50 pounds each, were made from cabbage not sold in the head. These were held at $3 per keg.

The mangolds yielded 648 bushels from one-half an acre, giving at this rate the enormous yield of 1,296 bushels per acre. Those raised were easily sold to farmers for feeding stock. The experience, so far as gained at Berlin, indicates that mangolds will stand very heavy dosing of sewage.[1]

In 1896, complaints having been made by the local board of health of Waterloo Township to the effect that the sewage of Berlin was creating a nuisance in Berlin Creek, the matter was investigated by a committee of the board, which reported in effect that the farm had been managed on more economical lines than was desirable, such misplaced economy being the chief cause of the nuisance complained of. From this point of view the committee of the Provincial board suggested that the town council and local board of health of Berlin be instructed to adopt sufficient and adequate means whereby the whole sewage of the town could be applied on the beds in succession and completely purified before flowing to the creek. After making several

[1] Refer to Eng. News, Vol. XXIX, April 6, 1893, and Vol. XXXV, June 11, 1896; and to Rept. Prov. Bd. Health, 1896.

other recommendations the committee concluded its report with the statement that the farm could be made productive without there being any reasonable ground for complaint.

Hamilton.—Purification works by chemical precipitation have been approved for this place by the Provincial Board of Health. In order to insure efficient operation, a committee of the Provincial board which examined the plans in October, 1896, reported that in its opinion the management of the works, when constructed, should be left to the care and supervision of the city engineer, who should also be made responsible for the subordinate engineer in charge. The committee believed that with such management an effluent can be poured into Hamilton Bay of a purity compatible with the best interests of the public health. The works are under construction at the present time.

London.—It is understood that plans for sewage disposal by intermittent filtration are about to be carried out at this place. The land selected for the disposal fields is sandy and stated to be well adapted for the purpose.

London Hospital.—The works at London Hospital were constructed in 1888 and 1889 under the general direction of the architect in chief of the Ontario department of public works.

Previous to the construction of the disposal works the sewage from the hospital debouched into a small stream tributary to the south branch of the Thames River, which flows through the city of London. The drainage area of this stream is so small that it becomes nearly dry during the summer. The population of the hospital is over 1,000, and the daily amount of sewage 60,000 gallons. It became necessary, therefore, that some method of disposal be used other than of allowing the flow of raw sewage into the brook. The plan as carried out involves the flow of sewage into a receiving tank, from which it is pumped, as required, onto the disposal area of 30 acres, situated not far away. The general method is intermittent filtration, supplemented by broad irrigation. For this purpose an area of about 5 acres at the highest portion of the disposal area was leveled and laid out in absorption ditches. The balance of the field has been provided with a main carrier and distribution ditches, for use as an irrigation area whenever the filtration area is overworked or whenever during the growing season the sewage can be profitably utilized thereon for crops.

The filtration area is divided into three sections, onto each of which the sewage is run for one day, thereby giving two days' rest for a section after each application. The details of this work may be found in various publications in regard to sewage disposal.

Ontario Agricultural College.—Sewage purification by treatment with porous carbon supplemented by filtration through land was carried out at this institution in 1889. The daily amount of sewage averages 3,000 gallons. On its way to the settling tank it receives about 12 pounds of ferozone precipitant daily, and is allowed to settle for twenty-four

hours. The effluent is discharged on the filtering ground, which consists of a flat bed of gravel, clay, and loam, 100 by 75 feet in area, divided into two beds, each of which receives on alternate days the sewage for twenty-four hours. These beds are underdrained with tile drains, laid to a depth of from 2½ to 3 feet.

Waterloo.—Waterloo is located 2 miles south of Berlin, the town described previously, with which it is connected by a tramway. The population in 1891 was 2,941. Sewage-disposal works by intermittent filtration were constructed at this place in 1895. For the final works provision has been made for ten filter areas. The soil is sand and gravel. Each bed is 132 by 200 feet, giving an area of 26,400 square feet per bed. This area also includes the embankments, so that the actual purification area is somewhat less. As at Berlin, the sewage will be delivered upon the land without a preliminary screening out of the solid matters, the experience so far gained at the neighboring town of Berlin having indicated that there is little or no necessity for screening. Up to April, 1896, the total expenditure was about $2,000. The cost of the land is stated at about $80 per acre.

Concluding the foregoing account of sewage-disposal plants in the United States and Canada, we wish to state again that in such extreme condensation as is needful in a paper of this kind many important details are necessarily omitted. Complete descriptions of these works would require several hundred pages.

PUBLICATIONS RELATING TO SEWAGE UTILIZATION AND DISPOSAL.

The following books, pamphlets, reports, etc., are in the author's collection and have been consulted frequently in discussing questions of sewage utilization and disposal. There is no pretense to completeness in this list, including, as it does, only such as have been brought together without special effort. The books here included are a fairly good beginning for a library of sewage utilization and disposal and some of the more important cognate questions.

Adams (Julius W.). Sewers and drains in populous districts. 8vo. New York, 1880.

Contains short chapter on sewage disposal.

American Public Health Association, Proceedings of.

American Society of Civil Engineers, Transactions of.

Association of Engineering Societies, Journal of.

Association of Municipal and Sanitary Engineers and Surveyors, Proceedings of. Vols. I–XXI.

Contain a large number of valuable practical papers on sewerage, sewage disposal, and river pollution in England, as prepared by the engineers of the various works. Many of these papers are indispensable to anyone who wishes to study the question from a practical point of view.

Austin (Henry). Report on the means of deodorizing and utilizing the sewage of towns. Paper; 8vo. London, 1857.

Discusses a large number of the more important questions in sewage utilization in such a way as to be of great value to the student of the present day.

Backhouse (Benjamin). An account of Liernur's sewerage system in its present state of development based upon personal inquiry. By the chairman of the city of Sydney Improvement Board. Pamphlet; 8vo. London, 1887.

Baker (Henry B.). Report on best method of disposition of excreta and waste matters, at Harbor Point, Michigan.

Baker (M. N.). Sewage purification in America. Paper; 12mo. New York, 1893.

Baker (M. N.). Sewerage and sewage purification. 16mo. New York, 1896.

Baumeister (R.). The cleaning and sewerage of cities—sewerage, sewage disposal, street cleaning. Translation; 8vo. New York, 1891.

A concise statement of the German views on sewerage, sewage disposal, and street cleaning. Contains illustrations and is especially valuable for the reader who wishes to survey the whole field of the German view without reading a large number of works. As remarked in the introduction, prepared by Rudolph Hering, the American reader should remember that this work was prepared primarily for German engineers and for the conditions prevalent in the German Empire.

Birmingham sewage inquiry. 8vo. Birmingham and London, 1871.

This report contains a very thorough review of sewage purification as it existed in 1871, together with description and cuts of the pail system as used in Liverpool, Manchester, Rochdale, Birmingham, etc. The reader should remember, however, in reading the old reports, that many of the appliances which are illustrated have been improved within recent dates, and that the statements and illustrations can only be safely taken after one has obtained full knowledge of the subject and consequent power of selection.

Birmingham system of refuse disposal. Printed by order of the Birmingham Health Committee. Pamphlet; 8vo. Birmingham, 1893.

Blythe (A. Wynter). A manual of public health. 8vo. London, 1890.

Blythe (A. Wynter). Lectures on sanitary law. 8vo. London, 1893.

Contains twelve lectures on sanitary law delivered by the author at the College of Medicine as part of the usual course of instruction in sanitary science. Examples of by-laws relating to offensive trades, the law relating to adulteration, etc., are given in the appendix.

Boston main drainage works. 8vo. Boston, 1885.

Contains a full account of the construction of the main drainage works of the city of Boston, where, by reason of the nearness of the ocean, it was deemed preferable to dispose of the city sewage by discharge at high tide into the waters of the lower harbor.

Boulnois (H. Percy). Municipal and sanitary engineer's handbook. 8vo. London, 1893.

Brookman (F. W.). Utilization of town refuse at Rochdale. Reprint from the Journal of Society of Chemical Industry, April 30, 1895. London, 1895.

Buck. Treatise on hygiene and public health. 2 vols. 8vo. New York, 1879.

Burke (N. R.). A handbook of sewage utilization. 12mo. London, 1872.

Burn (R. Scott). Outlines of modern farming. 6th edition. 12mo. London, 1888.

Treats extensively among other subjects of the utilization of town sewage, irrigation, etc.

Callis (Robert W.). Lectures on sewers. Large 8vo. London, 1686.

Contains a series of lectures on sewers as delivered by the author, at Grace Inn, in August, 1622.

Chandler (C. F.). Report on the waters of the Hudson River, made to the water commissioners in the city of Albany. Paper; 8vo. New York, 1885.

The author, in 1885, takes the ground that the Hudson River was at the time a proper water supply for the city of Albany.

Chicago drainage and water supply. Preliminary report of a commission consisting of Rudolph Hering, Benezette Williams, and Samuel G. Artingstall. Paper; 8vo. Chicago, 1887.

Clippart (John H.). The principles and practice of land drainage. 3d edition. 12mo. Cincinnati, 1888.

Connecticut State Board of Health, 1884 to 1895, inclusive.

These reports contain a large amount of original work on pollution of water supplies and stream pollution generally as performed under the direction of the State board of health during the period included.

Cooley (Lyman E.). The Lakes and Gulf waterway as related to the Chicago sanitary problem. Paper; large 8vo. Chicago.

Coplin (W. M. L. and Bevan D.). A manual of practical hygiene. 8vo. Philadelphia, 1893.

Corfield (W. H.). The treatment and utilization of sewage. 3d edition, revised and enlarged by the author and Louis C. Parks. 8vo. London, 1887.

In this work the question of sewage utilization is examined at considerable length, and many useful conclusions are reached.

Crimp (W. Santo). Sewage disposal works. A guide to the construction of works for the prevention of pollution by sewage of rivers and estuaries. 1st edition. 8vo. London, 1890. 2d edition. London, 1894.

Contains descriptions up to date of a large number of the more important English sewage disposal works.

Dempsey (G. D.). Drainage of lands, towns, and buildings. Revised edition with large additions of recent practices in drainage engineering, by D. Kinnear Clark. 12mo. London, 1890.

Denton (J. Bailey). Sanitary works and sewage utilization. Paper; 8vo. London, 1869.

Denton (J. Bailey). Ten years' experience in works of intermittent downward filtration. 8vo. London.

Dibdin (W. J.). Report of experiments on the filtration of sewage effluent (from the London main drainage works) during the years 1892–1895, inclusive. Paper; 4to. London, 1895.

Engineering News. From 1892 to 1897, inclusive.

This journal contains more or less complete descriptions of the more interesting and important of the American works.

Engineering Record.

This journal has published a vast amount of information in regard to sewerage and sewage disposal both at home and abroad, and in 1889 published an index to matter pertaining to sewerage and sewage disposal which had appeared in Vols. V to XVII (December, 1881–June, 1888). There has also appeared a large amount of matter in the volumes from XVIII to XXXIV (the current volume).

Framingham, Massachusetts. System of sewage disposal. A report of a committee on drainage and sewerage and construction of a sewerage system. Statement in detail of cost of construction, plans, etc. 8vo. South Framingham, 1889.

Frankland (Percy and Mrs. Percy). Micro organisms in water, their significance, identification, and removal. 8vo. London, 1894.

Contains a statement of the relation of sewage-polluted water to disease.

French (Henry F.). Farm drainage. The principles, practice, and methods of draining land, etc. 12mo. New York, 1884.

Gerhardt (William Paul). The disposal of sewage at isolated country houses. Paper; 8vo. Providence, 1890.

Gerhardt (William Paul). The disposal of household wastes. 16mo. New York, 1890.

Gerhardt (William Paul). Sanitary engineering. Reprint from the Journal of the Franklin Institute, June–August, 1895. Paper; 8vo. Philadelphia, 1895.

Gray (Samuel M.). Proposed plan of a sewerage system for the disposal of the sewage of the city of Providence. Made by order of the city council of the city of Providence. Paper; 8vo. Providence, 1884.

Contains an account of a large number of sewage purification plants abroad as visited by Mr. Gray, together with recommendations for the partial purification of sewage of Providence by chemical treatment, followed by its discharge into tide water at a point where it could not become a nuisance along the adjacent beaches.

Gray (Samuel M.). Report showing location and size of the main intercepting sewers of the city of Providence and other information called for by the common council by resolutions of various dates in 1886. Paper; 8vo. Providence, 1886.

Griffiths (A. B.). A treatise on manures. 12mo. London, 1889.

Hall (William Hammond). Irrigation in California. 2 vols. 8vo. San Francisco, 1888, 1889. A report on irrigation in California as made by the State engineer.

A good text-book of American irrigation practice.

Harris (Joseph). Talks on manures. New and enlarged edition. 12mo. New York, 1888.

Hawkshaw (Sir John). Report as commissioner appointed to inquire as to the purification of the river Clyde. Paper; 4to. London, 1876.

Contains information as to the pollution of the river Clyde and its tributaries as they existed in 1876.

Hazen (Allen). Filtration of public water supplies. 8vo. New York, 1895.

Contains data as to quality of filtering material, construction of filters, etc.

Hazen (Allen). A practical plan for sand filtration as a means of securing a better water supply to the city of Philadelphia. Report to the Woman's Health Protective Association of Philadelphia. Paper; 8vo. 10 pp. 1896.

Health in country homes. The disposal of sewage. A series of articles reprinted from the New York Evening Post. Paper; 8vo.

Health of Towns Commission. This commission made two reports—the first, 1844, published in two 8vo. vols.; the second, in 1845, also in two 8vo. vols.

These two reports may be taken as the beginning of sanitary science in England and in the civilized world generally. These reports should be studied by any person wishing to study the whole subject of sewage utilization, by way of showing the magnitude of the evil which has been combatted and greatly mitigated since 1844.

Hill (John W.). Sewage disposal and water supply. A paper read before the Ohio Society of Surveyors and Civil Engineers, January 18. 1893. Reprinted for private circulation. Paper; 8vo.

Hill (John W.). Water supplies for eight cities in relation to typhoid-fever rates. An address before the Society of Municipal Improvements, Chicago, October 9, 1896. Paper; 12mo. 8 pp. Cincinnati, 1896.

Hill (John W.). The hygiene of water. A lecture delivered before the Teachers' Institute, Cincinnati, Ohio, September 11, 1896. Reprint from the Dietetic and Hygienic Gazette, October, 1896. Paper; small 4to. 10 pp. 1896.

Hutchinson (Christopher Clarke). On the disposal of sewage sludge. A paper read before the Society of Chemical Industry, February 4, 1884. Paper; 8vo. London, 1884.

Institution of Civil Engineers, Proceedings of. Vols. I–CXX. 8vo. London, 1838–1895.

Contain a large amount of information on river pollution and sewage deodorization, filtration, interception, irrigation, manure, precipitation, and sewage utilization generally. Detailed subject indexes have been issued from Vols. I-LVIII and from Vols. LIX-CXVIII, to which reference may be made for nearly every phase of the subject as discussed in England for the last forty to fifty years.

Johnson (Samuel W.). How crops feed. A treatise on the atmosphere and the soil as related to the growth of agricultural plants. 12mo. New York, 1890.

Johnson (Samuel W.). How crops grow. A treatise on the chemical composition, structure, and life of the plant. 12mo. New York, 1890.

Jones (Charles). Refuse destructors. 2d edition. 8vo. London, 1894.

Contains detailed information as to the result of garbage destruction by fire, as well as a paper on the utilization of town refuse for power production, by Thomas Tomlinson.

Kiersted (Wyncoop). A discussion of the prevailing theories and practice relating to sewage disposal. 12mo. New York, 1894.

The author believes that the rivers of the country are, on the whole, the natural place for disposing of sewage. In his view the natural forces of nitrification will purify the sewage in streams somewhat the same as on land.

Kinnett (C. T.). Nature's hygiene. A systematic manual of natural hygiene. 4th edition. 8vo. London, 1894.

Krepp (Charles Frederick). The sewage question. A general review of all systems and methods. 8vo. London, 1867.

Especially devoted to showing the superiority of the pneumatic system of Capt. Charles Liernur.

Kuichling (E.). Report on the proposed trunk sewer for the east side of the city of Rochester, New York. Pamphlet; 8vo. Rochester, 1889.

Contains a résumé of the various methods of sewage disposal and leans to the conclusion that for the conditions existing in Rochester a chemical treatment would be preferable.

Latham (Baldwin). Sanitary engineering. A guide to the construction of works on sewerage and house drainage. 2d edition. 8vo. London, 1878.

This work was reprinted by Engineering News in 1877.

Lawes (J. Parry). Reports of sewer air investigations, as made to the London County Council. Paper. London, 1894.

Leffmann (Henry) and **Beam** (William). Examination of water for sanitation and domestic purposes. 12mo. Philadelphia, 1889.

Lehmann (K. B.). Methods of practical hygiene. 2 vols. 8vo. London, 1893.

Translated from the German by W. Crooks.

Local Government Board. Reports of the medical officer.

The reports of the medical officer of the privy council and local government board have contained for many years much information of interest and value relating to sewage purification and utilization. The student of the subject will find in these reports a vast amount of important matter. In the supplement to the report of the medical officer for 1891 may be found a study of enteric fever in the valley of the river Lee. In the supplement to the report for 1887 may be found papers giving full statistics of diarrhea and diphtheria in England. The first of these is a report by Dr. Ballard of the cause of the mortality from diarrhea which is observed principally in the summer seasons of the year in English communities, and the second is a statistical study by Dr. Longstaff on the geographical distribution of diphtheria in England and Wales. Dr. Ballard's statistical inquiry included the years from 1880 to 1888, while Dr. Longstaff's included the twenty-six years ending with 1880. The relation of these two diseases to sanitary conditions is set forth in many tables and diagrams with great clearness.

Lowcock (Richard Sidney). Experiments on the filtration of sewage. Excerpt from Proceedings Institution Civil Engineers, Vol. CXV. Paper; 8vo. London, 1893.

Mason (William P.). Water supply, chemical and sanitary. 8vo. New York, 1896.

Contains an excellent statement of drinking water as affected by sewage pollution in its relations to disease.

Massachusetts Drainage Commission, Report of. 8vo. Boston, 1886.

This commission was authorized by the Massachusetts legislature to consider and report systems of drainage for the Mystic, Blackstone, and Charles river valleys. In 1885 a report of great value was submitted, in which questions of stream pollution and sewage disposal are discussed at length. The engineer of the commission, Elliot C. Clark, also submitted a report in which he gave the details of the problem of prevention of stream pollution and methods of sewage purification as applied to the river valleys named. One of the best of the early American reports.

Massachusetts State Board of Health, Reports of.

This splendid series of sanitary reports now includes 27 volumes of annual reports and 2 special reports on the purification of sewage and water and on the examination of water supplies, besides special reports on the sewerage of the Mystic and Charles river valleys, and on the Metropolitan water supply of Boston, making 31 volumes in all. These are indispensable to any person who desires to study thoroughly the subject of sewage purification and utilization in the United States. Stream pollution, sewerage, and sewage disposal were first discussed in the Fourth Annual Report, and have been discussed in some phase ever since. In the Nineteenth Annual Report may be found the preliminary account of the special experiments on intermittent filtration carried out by the board at Lawrence.

Menzies (William). A treatise on the sanitary management and utilization of sewage. Large 8vo. London, 1865.

Metropolitan sewage discharge. Report of Royal Commissioners. 4 vols. of reports; minutes of evidence; appendixes, etc. 4to. London, 1884, 1885.

Presents every phase of question of disposal of sewage of London as it existed twelve years ago.

Metropolitan water supply, Report of Royal Commission on. 6 vols. General report; minutes of evidence; appendixes; index; plans, etc. 4to. London, 1893.

The most recent and extensive information as to pollution of streams and its effect on the water supply of the metropolis as applied to the rivers Thames and Lee, from which that supply is drawn.

Miles (Manly). Silos, ensilage, and silage. 12mo. New York, 1892.

A practical treatise on the construction of silos and the practical working of the process of ensilage.

Milwaukee, Wisconsin. Report of the Commission of Engineers on the collection and final disposal of the sewage and on the water supply of the city of Milwaukee. Paper; 8vo. Milwaukee, 1889.

Monson (Edward). The advantage of a separate system of drainage. Paper; 8vo. London, 1875.

Monson (Edward). Metropolitan sewage and what to do with it; a scheme of sewage disposal for the metropolis and the author's scheme of drainage for the lower Thames Valley, etc., the whole being a complete system of sewage clarification and purification. 8vo. London, 1883.

Moore (E. C. S.). Sanitary engineering. Occasional papers, Royal Engineers' Institute, being part of the professional papers of the Corps of Royal Engineers, Vol. XVII. 8vo. London, 1892.

Contains concise notes on various matters relating to sewerage and sewage disposal, as prepared specially for the use of the Royal Engineers.

Munroe (John M. H.). Composition and manurial value of filtered pressed sewage sludge. Reprint from the Journal of the Society of Chemical Industry, January 29, 1885. Manchester, 1885.

National Board of Health, Report for 1881.

This volume contains a report of the results of an examination made in 1880 of several sewerage works in Europe by Rudolph Hering. The information given, while extremely valuable in 1880, is of less interest now, by reason of being more recently covered. Mr. Hering gives a literature list which is still of value.

New Jersey State Board of Health, Vols. I–XVIII.

Contains information as to sewage-disposal works and stream pollution in New Jersey.

New York State Board of Health, Reports 1 to 16.

A large amount of information as to sewage disposal and stream pollution may be found in these reports, together with the detail plans of sewage-disposal plants thus far designed for towns in New York.

Palmberg (Albert). A treatise on public health and its applications in different European countries. Translated from the French. Edited by Arthur Newsholme. 8vo. London, 1893.

Contains a review of sanitary administration and legislation in the principal European countries.

Parks (Edward A.). A manual of practical hygiene. Edited by De Chaumont, with an appendix, giving the American practice in matters relating to hygiene, prepared by and under the supervision of Frederick N. Owen. 2 vols. Large 8vo. New York, 1884. From the last London edition.

Parks (Louis C.). Hygiene and public health. 12mo. Philadelphia, 1889.

Pennsylvania State Board of Health, Vols. I–X.

Contain many general discussions on stream pollution, sewerage, and sewage disposal.

Philadelphia Water Department, Annual Reports of the Chief Engineer, 1883 to 1886, inclusive.

These reports contain the results of an investigation as to the pollution of the water supply of the city of Philadelphia by sewage, together with the reports on additional supplies from unpolluted or nearly unpolluted sources, with methods of preventing pollution, etc. They may be referred to for much valuable information on the general question of pollution of streams and its attendant evils.

Philbrick (Edward S.). American sanitary engineering. 8vo. New York, 1881.

Philbrick (Edward S.). The disposal of sewage in suburban residences. Paper; 12mo. New York, 1883.

Platt (S. Sidney). Description of the sewage-disposal works at Roch Mills, Rochdale, England. Paper; 12mo. 4 pp. Rochdale, 1896.

Pollution of water supplies. Report of a committee of the American Public Health Association. Read at the annual meeting at Milwaukee, November 20–23, 1888. Paper; 8vo. Concord, 1889.

Provincial Board of Health of Ontario. Reports 1–4.

Contain information as to sewage-disposal works and stream pollution in the Dominion of Canada.

Rafter (George W.) and **Baker** (M. N.). Sewage disposal in the United States. 8vo. New York, 1893.

This work is dedicated to the health and prosperity of American cities, and contains descriptions and references to practically all the sewage-disposal works in the United States up to the summer of 1893.

Rauch (John H.). The sanitary problems of Chicago, past and present. Reprint from the Second Annual Report of the Illinois State Board of Health. Paper; 8vo.

Reeves (R. Harris). Sewer ventilation and sewage treatment. 12mo. London, 1889.

Contains description of special methods of chemical treatment and ventilation designed by the author.

Rivers Pollution Commission (first commission). 5 vols. 4to. London, 1866, 1867.

This commission made three reports. The first report deals generally with the best methods of preventing the pollution of rivers, with special reference to the conditions prevailing at that time on the river Thames. The second report deals with the river Lee. The third report deals with the rivers Ayr and Calder.

Rivers Pollution Commission (second commission). Report of the commissioners appointed in 1868 to inquire into the best means of preventing the pollution of rivers. 10 vols. 4to. London, 1870, 1871, 1872, 1874.

This commission made six reports in all. The first report, in two volumes, treats of the pollution of the basin of the rivers Mersey and Ribble and of the best means of preventing pollution therein. The second report is taken up with a description of the A, B, C process of treating sewage. The third report, in two volumes, discusses the pollution arising from the woolen manufacture and processes connected therewith. The fourth report treats of the pollution of the rivers of Scotland, and gives special consideration, among other subjects, to the pollution arising from paper-mill wastes, etc. The fifth report, in two volumes, treats of the pollution arising from mining operations and metal manufactures. The sixth report, in one volume, treats of the general subject of domestic water supply of Great Britain. In this report Dr. Edwin Franklin, the chemist member of the commission, has here worked out in detail the method of water analysis which he designated as the combustion method. A large amount of information about water supplies from cultivated and uncultivated areas and the contamination of water from manured and unmanured, cropped and uncropped land is given, the whole forming a vast body of sanitary information pertinent to present conditions.

Royal Sanitary Commission, Report of. Second report. 4to. London, 1871.

Contains a history of the English sanitary laws up to that date, with suggestions for new statute, etc.

Sanitary Institute, Transactions of. Vols. I–XII.

Contains many practical papers on sewerage and sewage disposal. 8vo. London.

Sewage disposal. Report of a committee appointed by the president of the local government board to inquire into the several modes of treating town sewage. Paper; 8vo. London, 1876.

Contains many details of sewerage work carried out in England to that date, with a large number of analyses of raw and effluent sewage at several sewage farms. In appendix No. 7 is given a list of a large number of patented processes for treating sewage and producing artificial manure therefrom, as taken out from between the years 1856 and 1875 inclusive. The report is also accompanied by a folio of plans, giving details of a number of the more interesting sewage-disposal works of that date.

Sewage disposal at Los Angeles, California. A report of the board of engineers upon the disposal of the sewage of Los Angeles city and its sewer system, presented to the mayor and common council of the city of Los Angeles, December 23, 1889. Paper; 8vo. 1889.

Contains the preliminary information as to sewage utilization at Los Angeles.

Sewage disposal at the London, Ontario, Asylum. Report of the Provincial Board of Health of Ontario. Paper; 8vo. Toronto, 1890.

Contains the report and detailed plans as submitted by Col. George E. Waring, jr.

Sewage disposal at the Rhode Island State institutions. Seventeenth Annual Report of the Board of State Charities and Corrections of Rhode Island, 1885. Paper; 8vo. Providence, 1886.

Contains the report and plans of Samuel M. Gray upon the disposal of the sewage of the State institutions at Cranston, Rhode Island.

Sewage disposal at the Rochester, Minnesota, State Hospital for the Insane. Sixth Biennial Report of the Trustees and Officers of the State Hospital, Rochester, Minnesota. 8vo. Minneapolis, 1890.

Contains report and detailed plans of the purification works at the Rochester Hospital.

Sewage farm competition of the Royal Agricultural Society of England. Report of judges appointed in the sewage farm competitions. Reprint from the journal of the Royal Agricultural Society. 8vo. London, 1880.

Sewage of the District of Columbia. Report by Rudolph Hering, Samuel M. Gray, and Frederick P. Stearns. Paper; 8vo. Washington, 1890.

Sewage of the Metropolis. Report from a select committee, ordered by the House of Commons to be printed July 14, 1864. Paper; 4to. London, 1864.

This committee was appointed specially to inquire into plans for dealing with the sewage of the metropolis (London) and other large towns with a view to its utilization in agriculture. The committee concluded that it is not only possible to utilize the sewage of towns, but that such an undertaking may be made to result in pecuniary advantage to the rate payers of the towns whose sewage is thus utilized. A large amount of evidence was taken by calling before the committee a number of the eminent engineers and English sanitarians of the day.

Sewage of Towns, Report from the select committee on. Two reports, in 2 volumes. First report ordered to be printed April 10, 1862, and the second report April 29, 1862. 4to. London, 1882.

Sewage of Towns Commission. Three reports. 8vo. London, 1858, 1861, 1865.

These reports contain the detail of elaborate investigations made by a royal commission appointed to inquire into the best mode of distributing the sewage of towns and applying it to beneficial and profitable uses. Elaborate cultivation and feeding experiments were pursued, extending over a period of several years, the results of which were presented in great detail in the second and third reports. In the appendix to the first report may be found an account of a visit made by a committee of the commission to Milan, Italy, for the purpose of examining the sewage utilization works which had been carried out at that place. This committee reported under date of December, 1857, that the experience of the irrigation around Milan adds a striking proof to those already obtained as to the value in agriculture of a command of pure water and of the immense increase of that value obtained by the addition of sewage combined with the higher temperature derived by the liquid in its passage through the town.

Sewage purification. Return of the particulars of the means adopted by local authorities for the purification or disposal of sewage, as made to the municipal authorities of the borough of Rochdale. 4to. 1872.

Contains details as to the population of towns, area of sewage farms or disposal areas, average rainfall of district, cost of land, number of years in operation, method of managing farm, information as to nuisances from effluent, etc. Also contains the particulars as to a large number of precipitating plants in operation in England in 1872.

Sewage treatment at the Barking and Crossness outfalls. Report by the engineer for the year 1894, ordered printed by the main drainage committee July 11, 1895. The same for the year 1893, ordered printed by the main drainage committee May 31, 1894. Five pamphlets in all. 4to. London.

Sewage utilization at the State Lunatic Asylum at Worcester, Massachusetts. Forty-seventh Annual Report of the Trustees, for the year ending September 30, 1879. Paper; 8vo. Boston, 1880.

Contains plans of the sewage utilization works as carried out in 1876 and as still in successful use at that institution.

Shedd (J. Herbert). Report on sewerage of the city of Providence. Paper; 8vo. Providence, 1874.

Slater (J. W.). Sewage treatment, purification, and utilization. 12mo. London, 1888.

Largely devoted to description and discussion of special processes of chemical purification. Contains a list of patents granted for sewage purification processes by chemical treatment, from 1886, inclusive. The total number of patents listed in that period is given at page 454, of which 11 have been taken out by the author of the work.

Snow (F. Herbert). Report on sewer assessments. Paper; 8vo. Brockton, 1894.

Staley (Cady) and **Pierson** (George S.). A separate system of sewerage, its theory and construction. Second edition; 8vo. New York, 1892.

Contains short chapter on sewage disposal.

Storer (F. H.). Agriculture in some of its relations with chemistry. 2 vols. 8vo. New York, 1888.

Professor Storer's two volumes contain a survey of the whole field of scientific agriculture to date. As regards sewage utilization, following the English views of ten to fifteen years ago, he is disposed to say that it can not be made commercially successful. His work should be consulted by every person interested in the subject.

Tidy (C. Meynott). The treatment of sewage. 16mo. New York, 1887.

Tieman (F.) and **Gartner** (A.). Die chemische und mikroskopisch-bakteriologische Untersuchung des Wassers. Paper; 8vo. Braunschweig, 1889.

Tottenham Local Board of Health. A report on the disposal of sewage of the district, made by the Tottenham local board in May, 1870. 8vo. London, 1870.

Turner (George). Report on the outbreak of enteric fever in the southeast of London. Made to the public health department May 18, 1892. Paper; 4to. London, 1892.

Verwaltungs-bericht des Magistrats zu Berlin. Bericht der Deputation für die Verwaltung der Kanalisations Werke.

This is the annual official statement of the committee in charge of the sewerage system of the city. It contains full details as to the management of the sewage farms and the various scientific observations carried out there. It is from these statements that the tables given by Mr. Roechling in his paper on the sewerage works of Berlin have been prepared. The last statement at hand is that of the year from April 1, 1892, to March 31, 1893.

Wanklyn (J. Alfred). Water analysis. Practical treatise on the examination of potable water. 7th ed. 12 mo. New York, 1890.

Wardle (Thomas). Sewage treatment and disposal. 8 vo. London.

While this work has no date on the title-page, the preface is dated June 30, 1893. Its author, Thomas Wardle, esq., is a practicing English chemist of standing, who has himself perfected chemical processes of purification. The work contains much valuable information in regard to recent sewage disposal, and may be profitably consulted, although it is largely devoted to showing the superior value of Mr. Wardle's methods of purification over all others.

Waring (George E., jr.). The sanitary drainage of houses and towns. 4th edition, revised and enlarged. 12mo. Boston, 1883.

An excellent exposition of many of the fundamental questions.

Waring (George E., jr.). Draining for profit and draining for health. 2d edition, 12mo. New York, 1883.

Waring (George E., jr.). Sewage disposal of isolated houses and large institutions. Reprint from the American Architect, March 12 to April 9, 1892.

Waring (George E., jr.). Modern methods of sewage disposal. 12mo. New York, 1894. A second edition has been published in 1896.

Waring (George E., jr.). Purification of sewage by forced aeration. Report of an experimental investigation of the value of the process of purifying sewage by means of artificially aerated bacterial filters. Paper; 8vo. Newport, Rhode Island, 1895.

Waring (George E., jr.). The disposal of a city's waste. Reprint from North American Review for July, 1895. Paper; 8vo.

Waring (George E., jr.). A report on the final disposition of the waste of New York by the department of street cleaning. Paper; 8vo. New York, 1896.

Water supplies of Illinois and the pollution of its streams. A preliminary report to the Illinois State board of health, by John H. Rauch, secretary; with 2 appendixes: (1) Chemical investigations of the water supplies of Illinois, by Prof. J. H. Long; (2) The Illinois River Basin in its relations to sanitary engineering, by Lyman E. Cooley.

The beginning of very valuable studies, which unfortunately for sanitary science have not as yet been continued.

Wheeler (W. H.). The drainage of fens and lowlands. 8vo. London, 1888.

Wilcox (L.). Irrigation farming. A handbook for the practical application of water in the production of crops. 12mo. New York, 1895.

Wilson (George). A handbook of hygiene and sanitary science. 5th edition. 12mo. Philadelphia, 1885.

Worcester, Massachusetts. Reports of the city engineer in relation to the disposal of the sewage of the city of Worcester, made in 1889, in response to a request of the joint standing committee of the common council on sewers.

Contains an interesting account of a number of foreign sewage disposal works visited by the city engineer, as well as opinions of B. S. Brundell and James Mansergh in regard to the probable success of agricultural utilization at Worcester in comparison with sewage utilization in England, basing their opinions on the statements submitted as regards climate, etc. The sewage disposal works at Worcester were completed and put in operation in 1890. More recent reports, those of the superintendent of sewers, give detailed information as to cost of operation and degree of purification obtained. They may be consulted for a complete exhibit of the working from month to month of such a chemical-purification plant.

Worcester sewage and the Blackstone River. Reports on the pollution of the Blackstone River by the Worcester sewage, etc., with a project for the purification of the sewage of Worcester, by Col. George E. Waring, jr.

The French literature on sewage disposal is quite extensive, but is necessarily omitted because of lack of space. A number of new works and reports in English, which have appeared since the compilation of this list, are also omitted because of lack of space.

INDEX.

	Page.
Albion, N. Y., sewage disposal at	67
Alliance, Ohio, sewage disposal at	75
Altoona, Pa., sewage disposal at	72–73
Amherst, Mass., sewage disposal at	42
Analyses of sewage	26–28, 44, 54, 63, 75
Andover, Mass., sewage disposal at	56
Arizona, sewage disposal in	82
Ashland, Wis., typhoid fever at	39–40
Atlantic City, N. J., sewage disposal at	69–70
Augusta, Me., sewage disposal at	41
Batavia, N. Y., sewage disposal at	65
Bath, N. Y., sewage disposal at	65
Berlin, Canada, sewage disposal at	85–88
Blackstone River, Massachusetts, pollution of	54
Boston, Mass., water supply of	47–50
Braintree, Mass., sewage disposal at	56
Brewsters, N. Y., sewage disposal at	62
Bridgewater, Mass., sewage disposal at	57
Bristol, Conn., sewage disposal at	59–60
Brockton, Mass., sewage disposal at	42–45
Brooklyn, N. Y., sewage disposal at	62–63
Buffalo, N. Y., typhoid fever at	39
California, sewage disposal in	82–85
Canada, sewage disposal in	85–89
Canton, Ohio, sewage disposal at	75–76
Central Falls, R. I., sewage disposal at	57–58
Chautauqua, N. Y., sewage disposal at	63–64
Chicago, Ill., sewage disposal at	38, 40–41, 79
Cobleskill, N. Y., sewage disposal at	67
Colorado, sewage disposal in	80–81
Colorado Springs, Colo., sewage disposal at	80
Concord, Mass., sewage disposal at	48, 56
Concord, N. H., sewage disposal at	41–42
Connecticut, sewage disposal in	20–22, 59–62
Cortland, N. Y., sewage disposal at	67
Cost of sewage-disposal works	63, 76
Cranston, R. I., sewage disposal at	59
Crops, use of sewage on various	45
Danbury, Conn., sewage disposal at	60
Danvers, Mass., sewage disposal at	56
Duluth, Minn., typhoid fever at	40
Dyestuffs, purification of	29–30
East Orange, N. J., sewage disposal at	70
East Taunton, Mass., sewage purification at	23–24
England, origin of sewage irrigation in	13
character of sewage in	14–15
Essex Fells, N. J., sewage disposal at	70
Far Rockaway, N. Y., sewage disposal at	64
Fertilizers, value of	37–38
Filter materials, experiments with	31–34
Flatbush, N. Y., sewage disposal at	67
Fonda, N. Y., sewage disposal at	68
Fort Plain, N. Y., sewage disposal at	67
Fostoria, Ohio, sewage disposal at	76
Foxboro, Mass., sewage disposal at	56
Fresno, Cal., sewage disposal at	82
Fulton, N. Y., sewage disposal at	68
Gardner, Mass., sewage disposal at	45–46
Genesee River, pollution of	71
Gowanda, N. Y., sewage disposal at	68
Great Lakes, pollution of	36–41
Greenfield, Mass., sewage disposal at	46
Hamilton, Canada, sewage disposal at	88
Hastings, Nebr., sewage disposal at	80
Helena, Mont., sewage disposal at	81
Hemlock Lake, New York, pollution of	64–65
Herkimer, N. Y., sewage disposal at	68
Holly, N. Y., sewage disposal at	68
Hyde Park, Mass., sewage purification at	23
Ilion, N. Y., sewage disposal at	68
Illinois, sewage disposal in	77–79
Intermittent filtration, purification by	34
Jamestown, N. Y., sewage disposal at	68
Kenton, Ohio, sewage purification at	25–26
Lake Calumet, Illinois, pollution of	77–79
Lake Cochituate, Massachusetts, pollution of	50–52
Lake Michigan, pollution of	38
Lake Wauremaug, Connecticut, pollution of	60
Lawrence, Mass., experiments at	15, 30–35
Lawrenceville School, New Jersey, sewage disposal at	70
Leadville, Colo., sewage disposal at	80–81
Leicester, Mass., sewage disposal at	56
Lenox, Mass., sewage disposal at	46
Litchfield, Conn., sewage disposal at	60
London, Canada, sewage disposal at	88
Long Branch, N. J., sewage disposal at	70
Lorain, Ohio, typhoid fever at	39
Los Angeles, Cal., sewage disposal at	82–84
Lyons, N. Y., sewage disposal at	68
Maine, sewage disposal in	41
Manchester, Conn., sewage disposal at	60
Manufacturing waste, purification of	27–35
Marlboro, Mass., sewage disposal at	46–47
Massachusetts, sewage disposal in	17–20, 23–24, 26, 42–57
Massachusetts board of health, experiments of	15, 27–35
cited	17–18, 27, 34, 41, 44, 54–55

	Page.
Massachusetts drainage commission cited	22
Medfield, Mass., sewage disposal at	48, 57
Menominee River, Wisconsin, pollution of	24–25
Menominee Valley, Wisconsin, sewage disposal in	79
Meriden, Conn., sewage disposal at	20–21, 61–62
Michigan, sewage disposal in	77
Millbury, Mass., sewage purification at	23
Milwaukee, Wis., sewage purification near	24–25, 38
Minnesota, sewage disposal in	79–80
Montana, sewage disposal in	81
Morris Plains Asylum, New Jersey, sewage disposal at	70–71
Mount Vernon, N. Y., sewage disposal at	69
Mystic Valley, Massachusetts, sewage disposal in	48–49
Natick, Mass., sewage disposal at	50–51
Nebraska, sewage disposal in	80
Neponset River, Massachusetts, pollution of	18–20
New Britain, Conn., stream pollution at	21
New Hampshire, sewage disposal in	41–42
New Jersey, sewage disposal in	15–17, 69–72
New Rochelle, N. Y., sewage disposal at	64
New York, sewage disposal in	62–69
Newell, F. H., letter of transmittal by	9
Norfolk County, Mass., sewage disposal in	51
Norristown, Pa., sewage disposal at	73
North Brookfield, Mass., sewage disposal at	51
North Tarrytown, Mass., sewage disposal at	69
Norwood, Mass., experiments at	28
Oberlin, Ohio, sewage disposal at	76–77
Ohio, sewage disposal in	25–26, 75–77
Ohio board of health cited	25
Oneida, N. Y., sewage disposal at	69
Ontario Agricultural College, Canada, sewage disposal at	88–89
Paper-mill wastes, purification of	27
Paris, Tex., sewage disposal at	74–75
Pasadena, Cal., sewage disposal at	84–85
Passaic River, New Jersey, pollution of	15–17
Pawtucket, R. I., sewage disposal at	58–59
Pegan Brook, Massachusetts, pollution of	50, 52
Pelham Manor, N. Y., sewage disposal at	69
Pennsylvania, sewage disposal in	72–74
Phœnix, Ariz., sewage disposal at	82
Pittsfield, Mass., sewage disposal at	57
Plainfield, N. J., sewage disposal at	71
Poughkeepsie, N. Y., sewage disposal near	65–67
Princeton, N. J., sewage disposal at	71
Providence, R. I., sewage disposal at	22–23, 59
Publications relating to sewage disposal, list of	89–98
Pullman, Ill., sewage disposal at	77
Quinnipiac River, Connecticut, pollution of	20–22
Reading, Pa., sewage disposal at	73–74
Redding, Cal., sewage disposal at	85
Rhode Island, sewage disposal in	22–23, 57–59
Rivers Pollution Commission of England cited	14, 22, 29
Rochester, Minn., sewage disposal at	79
Rochester, N. Y., sewage disposal at	69
Rockingham County, N. H., sewage disposal in	42
St. Johns, Mich., sewage disposal at	77
Salt Lake City, Utah, sewage disposal at	81–82
San Antonio, Tex., sewage disposal at	75
San Luis Obispo, Cal., sewage disposal at	85
Sands, mechanical analyses of	31–34
Santa Rosa, Cal., sewage disposal at	85
Saylesville, R. I., sewage purification at	23
Scioto River, pollution of	25–26
Sherborn Prison, Massachusetts, sewage disposal at	52
South Framingham, Mass., sewage disposal at	52–53
Spencer, Mass., sewage disposal at	57
Stockton, Cal., sewage disposal at	85
Stoneham, Mass., sewage purification at	26
Stream pollution, discussion of	15–22
Sudbury River, Massachusetts, pollution of	19, 46–47
Summit, N. J., sewage disposal at	71–72
Tannery wastes, purification of	28–29
Taunton River, Massachusetts, pollution of	24
Temple, Tex., sewage disposal at	75
Tewksbury, Mass., sewage disposal at	57
Texas, sewage disposal in	74–75
Trinidad, Colo., sewage disposal at	81
Typhoid fever, occurrence of	38–41
United States, distribution of sewage-disposal plants in	11–13
Utah, sewage disposal in	81–82
Vassar College, New York, sewage disposal at	65–67
Wakefield, Mass., sewage disposal at	57
Wallingford, Conn., stream pollution at	21
Waltham, Mass., sewage disposal at	52
Waterbury, Conn., sewage disposal at	21–22, 62
Waterloo, Canada, sewage disposal at	89
Wayne, Pa., sewage disposal at	74
Wayne County, Mich., sewage disposal in	77
Wellesley College, Massachusetts, sewage disposal at	53
West River, Rhode Island, pollution of	22–23
West Virginia, sewage disposal in	74
Westboro, Mass., sewage disposal at	53
Westfield, N. J., sewage disposal at	72
Weston, W. Va., sewage disposal at	74
Williams Bridge, N. Y., sewage disposal at	69
Winchester, Mass., sewage purification at	23
Windsor, Ontario, typhoid fever at	39
Wisconsin, sewage disposal in	24–25, 79
Wisconsin board of health, cited	24
Wool-scouring wastes, purification of	27–28
Woonsocket, R. I., sewage disposal at	59
Worcester, Mass., sewage disposal at	53–56
Yalesville, Conn., stream pollution at	21

55TH CONGRESS, 3d Session. } HOUSE OF REPRESENTATIVES. { DOCUMENT No. 280.

DEPARTMENT OF THE INTERIOR

WATER-SUPPLY

AND

IRRIGATION PAPERS

OF THE

UNITED STATES GEOLOGICAL SURVEY

No. 23

WATER-RIGHT PROBLEMS OF THE BIGHORN MOUNTAINS.—MEAD

WASHINGTON
GOVERNMENT PRINTING OFFICE
1899

UNITED STATES GEOLOGICAL SURVEY

CHARLES D. WALCOTT, DIRECTOR

WATER-RIGHT PROBLEMS

OF THE

BIGHORN MOUNTAINS

BY

ELWOOD MEAD

WASHINGTON

GOVERNMENT PRINTING OFFICE

1899

CONTENTS.

	Page.
Letter of transmittal	9
Introduction	11
Number of appropriations and acreage reclaimed	12
Value of water rights	13
Board of control	14
Water divisions and districts	17
Appropriations in Division II	18
District 2, Crazy Woman Creek	18
Decree of 1889	18
Objections to the decree	21
Excessive amounts claimed	24
District 3	28
Flow of Clear Creek	28
Early rights and their adjudication	31
Diversion across divides	32
Prairie Dog Creek	35
Summary of rights to water	36
Allowance for loss of water in transmission	38
Ownership in ditch not necessary to the acquirement of a water right	40
District 4	43
District 5	45
Little Tongue River	49
Appropriations in Division III	50
District 6	50
Order establishing priorities and amounts of appropriations of water from No Wood River and its tributaries	50
Reservoirs	55
Administrative questions	58
Index	61

ILLUSTRATIONS.

		Page.
PLATE	I.—*A*, North side of Cloud Peak; *B*, Bighorn Mountains as seen from Buffalo, Wyoming	11
	II.—Piney Creek below outlet of Cloud Peak Lake	32
	III.—Reservoir sites on Piney Creek: *A*, At Elk Lake; *B*, At Mead Lake	34
	IV.—North slope of Massacre Hill, illustrating erosion in ditches from Piney Creek	36
	V.—Timber flume in the canyon of Tongue River	44
	VI.—Beginning of dam at north end of Dome Lake reservoir	54
	VII.—Outlet of Kearney Lake reservoir site, on North Piney Creek	58
FIG.	1. Location of water districts in portions of Divisions II and III	17
	2. Irrigation systems on Clear Creek and tributaries	29
	3. Discharge of Clear Creek, near Buffalo, Wyoming, for 1894, 1896, and 1897	31
	4. Ditches diverting water from Piney Creek across Massacre Hill divide to Prairie Dog Creek	35
	5. Location of ditches on tributaries of Tongue River, Division II, district 4	44
	6. Location of ditches on North Fork of Tongue River, Division II, district 5	46
	7. Dome Lake reservoir	56
	8. Lakes at head of Piney and Goose creeks	57

LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF HYDROGRAPHY,
Washington, October 28, 1898.

SIR: I have the honor to transmit herewith the manuscript for a paper entitled Water-Right Problems of the Bighorn Mountains, by Prof. Elwood Mead, State engineer of Wyoming. This paper calls particular attention to the complications arising in the distribution of water as a result of the haphazard construction of small irrigation ditches. The problems encountered in this region are typical of those which are to be met in nearly every State of the West, or which will be met in the near future. The difficulties found in the area described are accentuated by the diversion of water from one stream across divides into other natural drainage lines, thus connecting and greatly complicating the water rights of one individual with those of others. The calling of public attention to these conditions will go far toward arousing enlightened sentiments in behalf of more comprehensive laws in other States and should bring needed support to the efforts of officials in their attempts to distribute equitably the waters of the flowing streams.

Very respectfully,

F. H. NEWELL,
Hydrographer in Charge.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

A. NORTH SIDE OF CLOUD PEAK.

B. BIGHORN MOUNTAINS AS SEEN FROM BUFFALO, WYOMING.

WATER-RIGHT PROBLEMS OF THE BIGHORN MOUNTAINS.

By ELWOOD MEAD.

INTRODUCTION.

The Bighorn Range is the most impressive feature in the landscape of northern Wyoming, and its scenic beauties are made the more attractive by the striking contrast they afford to the surrounding region. The traveler from the East or the South finds the clear, cold, perennial streams which flow from its snow-clad summits a grateful relief from the alkaline pools or dry sand channels which have to be largely relied on when journeying toward them. The lofty and rugged pinnacles of Cloud Peak (shown in Pl. I, *A*) are made all the more commanding because the bad-land hills, which form the summit of the Cheyenne watershed, are so commonplace and unattractive. West of the range is the Bighorn Basin, the lowest and most arid section of the State, where the dusty roads and gray stretches of sagebrush make a traveler look with longing at the snow-crowned, forest-clad slopes of the mountain barrier to the east.

In the arid States mountains, not plains, control agricultural development, and this isolated barrier, which rises near the middle of the northern boundary and extends southeast nearly to the center of the State, has done more to people the northern half of Wyoming than all other influences combined. Without it the section, now gridironed with ditches and supporting about one-fourth the population of the State, would be an open range supporting a few migratory flocks of sheep and herds of cattle. The latent wealth of the few hundred square miles of rocky, barren, and almost unoccupied land surface, over 8,000 feet above sea level, is far greater than that of any equal area in the valley below. This region gathers and stores the moisture which alone gives value to the land below. The perennial streams thereby created have, in their diversion and use, given employment to more people, attracted the investment of more capital, and created more problems to tax the wisdom of the lawmakers than has all the unimproved unirrigated farming land in the State.

The ease and cheapness with which the streams can be diverted, the fertility of the soil, and the exceptional value of the surrounding grazing land have made this section an attractive location for the home-

seeker of limited means. It is a region of small ditches and individual appropriators of water. On the eastern slope appropriation began before there were any laws governing the recording or establishment of rights thereto, while the isolation of the early settlers made them disregard or give little heed to water-right problems until the needs of users began to exceed the available supply; since then the multitude of rights, resulting from the haphazard location of ditches, has made a satisfactory settlement of many of these problems unusually difficult. Before discussing these problems a brief review will be given of the progress made in the twenty years which have elapsed since Manlius Redmond, a settler on Clear Creek, built the first ditch and became the pioneer farmer of the northern half of the State.

At that time the nearest railway station in the State was Rock Creek, on the Union Pacific, nearly 300 miles away. There was not a flour mill in the State, and the long, hazardous, and expensive trip necessary to secure the plow which turned the first furrow and the food for the men who worked on it added greatly to its cost. Reclaiming the desert under such conditions had many drawbacks, and the earlier ditches were of the crudest and simplest character. There was no attempt at any comprehensive projects. Each irrigator was a law to himself. Cooperative ditches or canals were rare exceptions. This explains the large number of ditches of record, and is the cause of many of the obstacles to the satisfactory division of water which confront those charged with this duty.

NUMBER OF APPROPRIATIONS AND ACREAGE RECLAIMED.

The records of the State engineer's office show that there are 1,051 adjudicated rights to the water flowing out of these mountains. There are also 269 claims which have been recorded and approved, but not adjudicated. In addition there are probably 100 ditches using water for which no claim has been filed. The adjudicated rights describe 139,478 acres of land to which these rights are attached in the orders of the board of control establishing them, and there are appropriations from Crazy Woman Creek aggregating 925.25 second-feet where the land irrigated is not described. Four flour mills have rights to water for power purposes aggregating 324.50 second-feet, and the several cities and towns of this region have adjudicated rights for power and domestic purposes amounting altogether to 80.6 second-feet.

Along the northern end of the range some promising placer fields have been discovered, and rights to 137.6 second-feet have been acquired with which to work them. The total volume of the adjudicated rights (3,455.4 second-feet) is in excess of the low-water discharge of the streams against which they are held, but is below the maximum discharge, so that the securing of a stable and adequate water supply for many of the irrigators holding adjudicated rights is a question of

storage. While all of the rights for irrigation, established by the board of control, are based on State surveys of the ditches and on sworn statements of the acreage irrigated by the appropriators, there is no question that these statements are somewhat in excess of the truth. Irrigation and reclamation are elastic terms. Spreading water over land to increase the growth of grass for pasturage purposes is irrigation and is so held by the board of control, but it is not the complete reclamation that is accomplished by cultivation. The tendency to augment the acreage actually watered is so common as to lead to the belief that it is unconscious. In the absence of exaggeration so gross as to constitute an injustice to other users, such a claim usually passes without protest unless it includes land which the State engineer's surveys show to be not susceptible of irrigation. The total acreage irrigated is, therefore, below the figures before given. A deduction of 10 per cent for exaggerated acreages and for areas which have only a surplus or flood-water supply would not be excessive, and would leave 125,000 acres as the actual area irrigated under rights established by the board of control. This is more than half the acreage given as irrigated in the entire State by the Tenth Census.

It is impossible to speak with equal certainty regarding the acreage irrigated under appropriations approved by the State engineer's office, but which have not yet been established by order of the board of control. In making a summary of these rights from the records of the engineer's office, all canceled permits, or those which have not complied with the requirements of the State law, have been excluded. This disposes of all the speculative filings which were made prior to 1894, during the time that no fee was required for the examination and record of applications to appropriate water. Since that time the stringent regulations governing the preparation of these filings have made applications so expensive that the tendency to make these for speculative purposes has almost disappeared. While the applications for permits recently approved do not represent actual utilization, they do represent projects based on reliable surveys, which are being carried out by people who are in earnest and who have sufficient investment in the work to make its completion probable. This is more nearly true of the appropriation of water from the streams of this region than of any other section of the State, as there are no large projects. These recorded and approved permits describe 214,000 acres of land for which irrigation appropriations are claimed, and 34 rights to water for power and domestic purposes.

VALUE OF WATER RIGHTS.

The value of the rights to the water which fills these ditches and fertilizes the land under them is an interesting subject for consideration. That they give to both ditches and land whatever value they have is unquestioned, because an empty ditch and an arid plain are alike

worthless. But while the right to water gives to the land whatever value it has, it does not make all values alike. Cost of maintaining ditches, ease of distributing water, fertility of the soil when irrigated, and the value and extent of the contiguous range are elements which have their influence. The fact that transfers of these rights have not thus far been recognized by the irrigation authorities of Wyoming has prevented any transactions of this character, so that we have to go to surrounding States for statistics on this subject. A recent sale of a right to 78 second-feet in one of the streams of northern Colorado is perhaps the best illustration of the present value of this form of property. In this sale nothing was sold but the right to take water from the stream. The ditches and lands by which it was conducted remained in the possession of the original holders. The right was moved several miles from its original location and required another ditch for the diversion of the water, and yet sold for a little more than $250 per second-foot. Its value was also lessened by the fact that the purchasers knew that the sale would be contested and that the expense of litigation to establish the legality of the transfer would have to be paid by them. The price paid, therefore, was far below what the property would have brought had the sellers been able to give an unquestioned title to the property, and is not, I think, above the value of an unquestioned right in the Bighorn Mountains. If this is true, the value of the adjudicated rights to the water of this range is already over $1,000,000. That this is destined to be greatly augmented in the near future is beyond question. The commercial importance of the water rights, therefore, makes their legality and the measures devised for their enforcement a subject of great economic interest.

BOARD OF CONTROL.

Under the constitution of Wyoming the board of control is intrusted with the supervision and control of all public waters of the State and of their appropriation, diversion, and distribution. Its administrative powers are therefore very broad. It has not only to determine rights to streams, but to enforce those rights afterwards. It has five members. These are the State engineer, who is president, and the four division superintendents. At the outset the board endeavored to outline clearly and definitely its views of what was necessary to complete or perfect a title to water, and so to simplify the methods of taking proof as to enable all water users to know what was required and to prepare and submit it at the least possible outlay. In pursuance of these views the board adopted and published the following governing principles:

1. In order to constitute a valid appropriation the water must have been used for some beneficial purpose, and in the case of appropriation for irrigation the water must have actually been applied to the land.

2. The amount of an appropriation is governed by the volume used and by the requirements of this use—in the case of appropriations for irrigation, by the needs of the land reclaimed.

3. Where reasonable diligence is shown in the construction of ditches and utilizing water, the appropriation dates from the beginning of work on the ditch, the survey to be considered as part of such work; where reasonable diligence is not shown, the appropriation dates from the utilization of the water.

4. Priority of appropriation gives priority of right, except in the case of appropriations made between 1888 and 1891, during which time the law made appropriation for domestic use a preferred priority.

5. Appropriations for irrigation are restricted to 1 cubic foot per second for each 70 acres irrigated. While this does not necessarily apply to lands reclaimed before the enactment of the State law, no appropriation for a larger amount has been made, because in all cases so far considered this volume has appeared ample.

6. Transfers of rights to water made in advance of any adjudication, either by the courts or by the board, are not recognized, the reason being that parties had not such ownership as would enable them to give valid title to the water sold. No transfers involving changes in location or character of use have been recognized.

As the operation of these principles is uniform, and as the facts on which any appropriation rests are in all cases the same, it was possible to prepare a blank form of proof for the guidance of irrigators, and in that way to simplify both the labor of preparing proofs and of the board in their subsequent examination. The following is the form adopted:

PROOF OF THE APPROPRIATION OF WATER.

From ———, Division No. ——.

State your name.

1. Post-office.

2. State the use to which the water has been applied.

3. State the means of diversion employed.

4. If through a ditch, state its name.

5. State (*a*) the date of the survey of the ditch or other distributing works through which the water claimed is diverted; (*b*) the date when the construction of such ditch was begun and when completed.

6. If any enlargements were made, state the date when begun and the date when completed.

7. State the dimensions of the ditch as originally constructed and as enlarged, and if measured by the county surveyor under the provisions of the act of 1886, give the results of such measurements.

8. State the name of person, association of persons, or corporation who built the ditch or canal, and the name or names of its present owners.

9. If water is claimed for irrigation, give the legal subdivisions of land owned or controlled by you for which an appropriation is claimed.

10. State the nature of your title to the above-described land; and if not owned by you, give the name of the owner and the nature of the possessory right which you exercise.

11. State the year when water was first used for irrigation or other beneficial purposes, and by whom.

12. If for irrigation, give the number of acres watered the first year, giving the legal subdivisions on which used and, as near as may be, the acres irrigated in each subdivision.

13. State the number of acres watered each subsequent year, and give the legal subdivisions on which the water was used and, as near as may be, the acres irrigated in each legal subdivision.

14. State the number of acres irrigated from said ditch in 189—, and give the legal subdivisions on which water was used and, as near as may be, the acres irrigated in each subdivision.

15. State the acreage said ditch is capable of watering, give the legal subdivisions of land which it can be made to irrigate, and state who owns said land.

16. State your proportionate interest in said ditch.

(16) The plat prepared by the State engineer is hereby accepted as showing correctly the location of the ditch and the land which can be irrigated therefrom.[1]

17. When does your irrigation season begin and when does it end?

18. If water is used for other purposes than irrigation, state the nature of such use and the time when such use began.

19. How much water is required for such purpose?

20. During what months is the water used?

21. Have you or any other claimant of said appropriation filed a claim to water in the office of the county clerk? If so, give date of filing and the name of the party or parties interested in said claim.

22. Have you had sufficient water each year since the use for which an appropriation is claimed began?

23. If not, state the years of scarcity, the months when the supply was insufficient, and the reason of such scarcity.

I hereby certify that the foregoing affidavit was read to the affiant in my presence before he signed his name thereto; that said affiant is to me personally known (or has been satisfactorily identified before me by ——— ———), and that I verily believe him to be a credible person and the person he represents himself to be; and that this affidavit was subscribed and sworn to before me at ———, on this —— day of ———, 189–.

———— ————,
Division Superintendent.

DEAR SIR: Your attention is called to the inclosed proof of appropriation. It is the intention of the law and also of the board of control to make the adjudication of rights to the use of water as inexpensive to the appropriator as possible. Consequently you are requested to cooperate with the division superintendent to whom you submit your testimony to the extent that you prepare yourself to answer all questions readily and accurately before the day set for submitting said testimony.

Your special attention is called to those questions whose answers indicate the date of your appropriation and use of the water, and to the acreage of land irrigated and description thereof.

By complying with this request you will not only facilitate the taking of testimony, but will insure the correct establishment of the respective rights and possibly prevent expensive and aggravating litigation.

Yours truly,

———— ————,
Division Superintendent.

[1] In case there is objection to the official plat, the parties objecting must, when giving proof, file a written statement of the reasons therefor, and must within thirty days file with the division superintendent a map of said ditch and irrigated lands, with affidavit of surveyor, giving date of survey, attached thereto.

WATER DIVISIONS AND DISTRICTS.

In order that each of the more than 1,000 holders of water rights shall obtain his share of the common supply there must be some officer to see that the rights are enforced and protected in times of

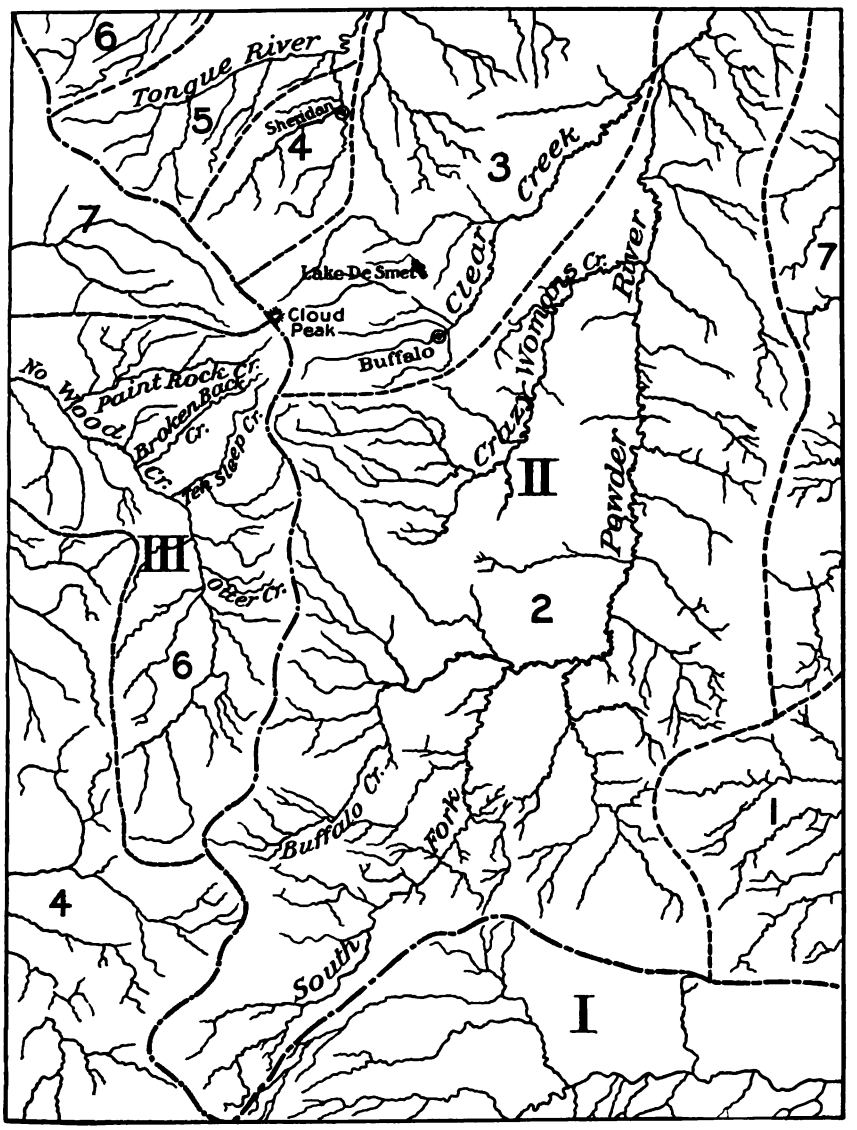


FIG. 1.—Location of water districts in portions of Divisions II and III.

scarcity. For convenience, and in order to make the work more effective, the entire State has been divided into four parts, called water divisions, and these divisions have been subdivided into dis-

tricts, there being at present forty districts in the four divisions. The boundaries of divisions are fixed by statute, those of districts by orders of the board of control, both being determined by drainage lines. The officer in charge of a division is called a water superintendent. He has general control of the work of the water commissioners, which is the title of the officers in charge of districts. The limits of a district are determined by the work to be done. The greater the number of ditches and the more variable the supply the smaller the territory a commissioner can supervise.

The Bighorn watershed forms part of two divisions, the eastern slope being in Division II, and the western in Division III. The portion in Division II is subdivided into five districts, numbered from the south northward 2, 3, 4, 5, and 6. The portion in Division III is subdivided into districts 4, 6, and 7. Fig. 1 shows the location and boundaries of the several districts.

Adjudications of rights to water have been had in districts 3, 4, and 5 of Division II, and in district 6 of Division III. Partial adjudications have been had in districts 2 and 6 of Division II. In the unadjudicated districts, or parts of districts, there is still a surplus water supply, rendering the services of a commissioner unnecessary and permitting further delay in the determination of rights.

APPROPRIATIONS IN DIVISION II.

DISTRICT 2, CRAZY WOMAN CREEK.

In 1889 scarcity of water in Crazy Woman Creek, a tributary of Powder River, led to an adjudication of rights thereto. Wyoming was then a Territory, and the procedure was had under the irrigation law of 1886. Under this law the testimony of appropriators was submitted to a master commissioner, appointed by the judge of the district court, and the final decree was based upon his findings. The outcome was not satisfactory. Water commissioners say that the decree can not be enforced because it does not conform to physical conditions, while late appropriators complain that the earlier priorities are for excessive amounts. The reasons for these objections and the basis of the master commissioner's findings can best be understood from an analysis of the decree. As it deals with the most important and most controverted water-right questions, not of Wyoming alone, but of all the arid States, it merits discussion. The decree, known as "John R. Smith, etc., *v.* Henry W. Devoe, etc.," reads in part as follows:

DECREE OF 1889.

This cause coming on for hearing upon the motion to confirm the report of the special commissioner, made at the present term, and upon the whole case, and the court being sufficiently advised, it is now adjudged that said report of the special commissioner be confirmed, and no exceptions having been filed or taken thereto, that the several findings of the commissioner be approved and confirmed,

and that they be taken, decreed, and held in all respects as the findings of this court in respect to each ditch and canal set out and reported in said report, numbered as to ditches and priorities in the appropriation of water, for beneficial purposes, from Crazy Woman Creek and its several tributaries, respectively, from 1 to 27, inclusively, and that the owner or owners of said several ditches and canals are, and shall be entitled, by original construction and the enlargement of their respective ditches and canals, to priority in the appropriation of water from said Crazy Woman Creek and its tributaries to the extent and in the order hereinafter set out.

PRIORITY NO. 1.

James A. Dowlin, the owner of said ditch by virtue of the construction thereof, shall be entitled, through said ditch, to so much water from Billy Creek, one of the tributaries of Crazy Woman Creek, as may be necessary and useful to irrigate 160 acres of land lying thereunder, not to exceed 8.65 cubic feet of water per second of time, and the same shall be designated and known as priority No. 1.

PRIORITY NO. 2.

That John R. Smith and Agnes D. Smith, the owners of the "John R. Smith ditch" by original construction thereof, shall be entitled, through said ditch, to so much water from Crazy Woman Creek and its several tributaries as may be necessary and useful for the irrigation of 1,200 acres of land lying thereunder, not to exceed 67.08 cubic feet of water per second of time, and the same shall be priority No. 2.

PRIORITY NO. 3.

That the Wyoming Land and Cattle Company, corporation, being the owner of what is known as the "North Fork ditch," taking its water from the North Fork of Crazy Woman Creek, by original construction thereof, shall be entitled through said ditch to so much water from said North Fork of Crazy Woman Creek as may be necessary to irrigate 800 acres of land owned by said company and lying under said ditch, not to exceed 30 cubic feet of water per second of time, and the same shall be priority No. 3.

The wording in the case of the remaining priorities is essentially the same, with the exception of the names of owners, ditches, and other details. The principal facts are given in the table on page 23. In the following table are the dimensions of the several ditches mentioned in the order and decree in this case and given in the report of the special commissioner.

Dimensions of ditches taking water from Crazy Woman Creek.

Priority number.	Name of ditch.	Average dimensions.			
		Top width.	Bottom width.	Depth.	Grade per mile.
		Feet.	*Feet.*	*Feet.*	*Feet.*
1	Billy Creek	7	5	1	7.2
2	John R. Smith	7.5	5	2.75	12
3	North Fork	.....	4	1.5	24
4	Harris No. 1	6	4	1.50	6.25
5	Kingsbury No. 1	2	1	1	73.95
6	Halt	5.5	3.5	1	16.5
7	Red Bark	9.5	7.5	1.2	12.7
8	Moreton	6.2	4	1.1	19
9	Cook	10	6	1.8	8
10	North Fork of Crazy Woman	7	4.5	2	4.5
11	Muddy Creek	6	4	1	5
12	Px	7.6	5	1.3	5
13	Kingsbury No. 4	2	1	1	29.94
14	Kingsbury No. 3	2	1	1	29½
15	Kingsbury No. 2	2	1	1	71½
16	Kennedy	*a* 7.1	.....	2.3	5.3
17	Dick	8.5	5	1.75	10
18	Burton, Kelly Creek	*b* 1.5	.....	1	15
19	Blue Gap	7.5	5.5	1	23
19½	Teddy Miller	13.75	7	2.25	12
20	Fort Collins	20	10	3.7	3.17
20½	North Fork (*c*)	8.5	5.5	1.5	24
21	Devoe No. 1	14	10	2	8
22	Devoe No. 2	10	8	2.5	5.28
23	Canton, Kelly Creek	5	3	1.5	5.28
24	Thompson Brothers	6.5	3.5	1	20
25	Thompson & Matthews	*d* 9	5	1	(*e*)
25½	Moreton enlargement	.....	.....	1.9	5.28
26	Mitchell & Long	.....	6	1.5	4
26½	Kennedy enlargement	11.7	7.1	2.3	24
27	Harris No. 2	.....	3	1	6.28

a Average width as originally constructed.
b Average width.
c Enlarged by Covington and Mays.
d Average width as enlarged.
e Grade 4 feet to the mile part of the way and 15 feet for the remainder.

OBJECTIONS TO THE DECREE.

The water described in this decree would suffice for the irrigation of between 50,000 and 75,000 acres of land even under the wasteful methods which prevail. The property disposed of was of great value. If a second-foot of water is worth $250, rights to 900 second-feet are of enough importance to warrant an inquiry into the methods by which they were acquired. Nothing is more indispensable, if we are to avoid disastrous controversies, than to have the acts by which a right to water is secured clearly defined and the limitations on that right definitely prescribed by law. Every user of water wishes to know how the title thereto is to be secured, while everyone interested in the growth and success of irrigated agriculture wishes to be certain that the commodity on which its success depends shall not be wastefully or fraudulently transferred to private or speculative owners. The results of this adjudication have apparently not answered either of the questions clearly or to the satisfaction of those directly concerned.

Controversies over the legality of these rights and over the discretionary authority of the water commissioner in enforcing the decree began the first season of its operation and still continue. That all should have agreed was out of the question. The Territorial law was both indefinite and contradictory in its provisions. Those claiming rights were not agreed either as to the meaning of the law or in their views of an irrigator's needs. Nor was the method of taking proof calculated to disclose the facts on which a just or satisfactory settlement of these rights must rest. There was no measure of the flow of the stream. There was no survey of the ditches, of the lands irrigated, or of the lands which could be irrigated. There was no proof of the actual volume of water diverted or of the needs of the land for which its use was claimed. All that was required in this disposal of public property was for each individual claiming a right therein to file proof of the building of a ditch and his estimate of the volume it would divert. The first objection to this was the lack of knowledge of the claimants themselves. Not one of them knew accurately the carrying capacity of his ditch or the volume needed to reclaim an acre of land. To all the expression "cubic foot per second" was an almost meaningless term. It would have meant just as much if the volume had been expressed in liters. Granting that the desire of all was to claim only what they were entitled to, their success in doing this would be wholly accidental. Nor was the submission of these statements to a judge or a commissioner having no greater practical knowledge than the irrigators themselves a wise provision. The questions to be determined were physical, not legal, and without some knowledge of either the volume which the stream carried or the water used on an acre of land these officers were in no way prepared to pass on the reasonableness of the claims.

In the absence, therefore, of a contest among the claimants themselves, by which the facts would be disclosed, it was possible for claims to be filed and approved which would establish rights to many times the volume used or, on the other hand, which would be below the claimants' real needs. Both of these results actually occurred in this adjudication. In saying this there is no desire to reflect on anyone. The outcome of this adjudication will compare favorably with that of most decrees rendered under this or similar laws elsewhere. What is desired is to explain at the outset that a law which gave the court no power to get at the facts by an impartial examination, but which, on the contrary, made the disposal of a stream depend almost wholly on the knowledge or honesty of those claiming it, could scarcely lead to anything but dissatisfaction, if not injustice.

It would seem that in fixing the volume of these rights the reasonableness of the claims should have been looked into and some uniform test applied by which their legality or necessity could be determined. The importance of this proceeding and its influence on further development was very great. This was a final transfer of a stream from public to private control. It was the surrender by the State of a part of its most valuable property and on the use of which its ultimate population and wealth depend. Realizing this fact, as all thoughtful minds do, it hardly seems reasonable that an ex parte claim should have been accepted without question and made the basis of the grant of a water right. To give every claimant all he asked without inquiry as to his needs or the work actually done to entitle him to anything would seem to be so unwise as to need no discussion. It makes the expression "adjudication" a farce. It will be seen, however, from an analysis of the decree that this is practically what happened. The statute required the evidence of claimants to disclose the capacity of the ditch diverting water and the acreage of land which could be irrigated, and the implication seems fair that the intention of its framers was that this proof should guide the court in fixing the amounts of appropriations. If this is correct, then, under this law, the amount of the appropriator's right to water should have been determined by two facts: First, the capacity of the ditch or canal to divert water from the stream; second, the volume which had actually been applied to beneficial use and the requirements of that use. The language of the decree in its opening paragraph would seem to imply that the construction of ditches alone gave appropriators their rights and that the application of water to a beneficial use was not deemed essential. The portion of the decree on which this statement is based is as follows:

> And that the owner or owners of said several ditches and canals are, and shall be, entitled by original construction and the enlargement of their respective ditches and canal to priority in the appropriation of water from said Crazy Woman Creek and its tributaries to the extent and in the order hereinafter set forth.

If rights were based on the construction of ditches, it would seem that the amounts appropriated should have been fixed by their capacity. To determine whether or not this was done the capacity of these ditches was computed. The dimensions given in the decree were assumed to be correct, and the discharge was determined by the use of Kutter's formulæ, a uniform coefficient of roughness of 0.025 being assumed. This would give a discharge above the actual flow for all except the largest ditches, because the small ones are poorly built, with rough sides and sharp and irregular curves. In the table which follows the computed capacity and the volume decreed are both given, with the difference between such appropriation and the discharge of the ditch:

Capacity of ditches taking water from Crazy Woman Creek and volume of water allotted by decree of 1889.

Priority number.	Name of ditch.	Name of appropriator.	Volume allotted in decree, in cubic feet per second.	Computed capacity of ditch, in cubic feet per second.	Excess of allotment over computed capacity of ditch.	Deficiency of allotment under computed capacity of ditch.	Number of acres watered or proposed to be watered.	Number of acres to each cubic foot per second allotted.	Total volume allotted, in cubic feet per second.
1	Billy Creek	J. A. Dowlin	8.65	16.20	.....	7.55	160	18.5	8.65
2	John R. Smith	John R. and Agnes Smith	a67.03	59.20	7.83	.....	1,200	17.8	75.68
3	North Fork	Wyoming Land and Cattle Co.	30	18.60	11.40	.....	800	26.6	105.68
4	Harris No. 1	W. Harris	12.2	14.25	.....	2.05	150	12.3	117.88
5	Kingsbury No. 1	D. A. Kingsbury	3.75	3.36	.39	.....	160	43.8	121.63
6	Holt	Wyoming Land and Cattle Co.	8.20	12.60	.....	4.40	150	18.3	129.83
7	Red Bark	B. J. and J. M. Scott et al.	37.4	18.70	18.70	.....	800	20.8	167.23
8	Moreton	Moreton Frewen	22.32	28.05	.....	5.73	400	17.9	189.55
9	Cook	Orrin Cook et al	33.55	31.68	1.87	.....	3,300	98.3	223.10
10	North Fork of Crazy Woman.	J. A. Dowlin	28	23	5	.....	300	10.3	251.10
11	Muddy Creek	do	8.4	8	.40	.....	300	35.7	259.50
12	Px	C. Basch and O. Speral	17.9	14.74	3.16	.....	200	11.1	277.40
13	Kingsbury No. 4	D. A. Kingsbury	2.35	1.92	.43	.....	300	127.6	279.75
14	Kingsbury No. 3	do	2.29	3.03	.....	.78	300	133.3	282
15	Kingsbury No. 2	do	3.6	3.04	.56	.....	160	44.4	285.60
16	Kennedy	R. Kennedy et al	32	37.56	.....	5.56	.....	.....	317.60
17	Dick	Powder River Cattle Co., M. Frewen.b	12.32	28.48	.....	16.16	600	48.7	329.92
18	Burton, Kelly Creek.	John Burton	3.6	1.80	1.80	.....	160	44.4	333.52
19	Blue Gap	Little North Fork Ditch Co.	26.5	20.15	6.35	.....	1,500	56.6	360.02
19½	Teddy Miller	F. G. S. Hesse	84.45	58.25	26.20	.....	1,160	13.7	444.47
20	Fort Collins	Fort Collins Land and Improvement Co.	210	166.50	43.50	.....	21,000	100	654.57
20½	North Fork	J. May and C. Covington	25	63	.....	38	800	32	679.47
21	Devoe No. 1	H. W. and C. M. Devoe	60.10	72	.....	11.90	2,000	33.3	739.57
22	Devoe No. 2	do	78.11	58.05	20.06	.....	3,000	38.7	817.68
23	Canton, Kelly Creek.	F. M. Canton	10.50	10.20	.30	.....	100	9.5	828.18
24	Thompson Bros.	F. S. and G. F. Thompson.	17.3	16	1.30	.....	160	9.2	845.48
25	Thompson & Matthews.	do	12	10.50	1.50	.....	800	66.7	857.48
25½	Moreton enlargement.	F. G. S. Hesse	45.72	59.33	6.30	.....	4,000	85.3	903.20
26	Mitchell & Long	B. Long, M. F. Mitchell	25	14.40	10.60	.....	1,200	48	928.20
27	Harris No. 2	W. Harris	10	9	1	.....	100	10	938.20

a Based on computation made in State engineer's office. b All the land owned by them.

While rights may have been acquired through the building of these ditches, the volumes decreed were manifestly not based on their capacity. Appropriator No. 1, after building a ditch to carry 16 feet, was given only a fraction over half that amount, while in contrast thereto the third appropriator was given 11 feet more than his ditch would divert. The seventh appropriator was given 2 second-feet for each foot the ditch could carry, while the seventeenth was cut down to less than half what had been or could be taken from the stream. Priority No. 18 was favored with a double allowance, while No. 20½ got only half a loaf. Some of the appropriations agree approximately with the volume which the ditch could divert, but the number which are either far above or far below shows that this agreement was accidental and not based on any investigation of this question.

EXCESSIVE AMOUNTS CLAIMED.

Nearly all recent laws and decisions are agreed that simply diverting water does not of itself complete a right to it; that in addition the water so diverted must be applied to some beneficial use. If this test be applied to appropriations for irrigation, the actual acreage reclaimed might properly be taken as the measure by which the volume appropriated should be determined. All of these appropriations are for this purpose, and all except one of them, No. 16, states the acreage to be irrigated, and in the excepted case it is restricted to the land owned by the claimants. A casual inspection of the number of acres irrigated and the amount decreed shows that the need of the land had no weight in fixing these rights. While the measurements of the water used in irrigating an acre of land have not as yet taken the range or embraced all the conditions needed to fix the absolute volume to be used on that area, enough have been made to show the approximate limits of such use. In a series of tests begun by the State engineer and continued by the State University of Wyoming there was not a single instance in which the duty of a second-foot fell below 80 acres. As these tests were made in widely separated localities, embraced a wide range of crops, and were continued for five years, this may fairly be taken as a limit of the actual needs of irrigation, and the State legislature has, since this decree was rendered, made any appropriation in excess of 1 second-foot to 70 acres illegal.

The land along Crazy Woman Creek can be irrigated with less water than is required in some of the localities where the volume used was measured, and there is no reason to question the statement that a duty of 1 second-foot to 80 acres is below rather than above the actual practice along the stream. But whether this be true or not, it is certain that the need of 1 acre is approximately the same as that of every other acre. There is so little variation in the soil and in the crops grown, that sufficient water for one 80-acre tract is enough for any other equal area along the same stream.

This fact could not have been considered in fixing these rights. In the table given, one column gives the acres to be irrigated; in the next column are the acres for which 1 second-foot of water was decreed. It will be seen that the first appropriator is given 1 second-foot for each 18 acres of his land, or at least four times the volume needed, while the fourteenth appropriator is required to spread a second-foot over 133 acres. When the owner of priority No. 20 found he was allowed only 1 second-foot for 100 acres, while his neighbor, owning the twenty-seventh, was given the same volume for 10 acres, he could not be blamed for objecting to the discrimination.

All of these awards are for a continuous flow for the entire year. In practice, however, the use of water in irrigation extends over a period of only three to four months. Assuming one hundred days to be the time of actual need, the irrigator under priority No. 1 is allowed water enough to cover his land to a depth of 10.8 feet, while the irrigator under priority No. 14 can cover his land with only 1.5 feet. The irrigator under priority No. 24 can, if he desires, submerge his farm under nearly 22 feet of water, while the appropriator under priority No. 13 can cover his with less than that many inches.

The excessive volumes of these appropriations make it manifest that the necessities of the land irrigated had no more to do with determining the volume decreed than had the size of the ditches. It is necessary to look further, therefore, to learn the reason for making some rights exceed the capacity of ditches and others fall below, and for allowing some appropriators more water for 80 acres than was given others for 800.

In 1886 a law was passed requiring parties claiming appropriations of water to file in the county clerk's office a statement of their claim. This law required that the statement should contain a description of the ditch, the name of the stream, and the number of acres lying under the ditch and irrigated or proposed to be irrigated. In the same law was a provision for a similar statement of claim for proposed ditches, which required any party intending to appropriate water to file a similar statement with the county clerk. It contained the same provisions as the section relating to existing ditches, with several additional ones relating to protection of existing rights and fixing the time for beginning of work, together with the following ambiguous and misleading clause:

> And from the time of filing any such statement water sufficient to fill such ditch or ditches and to subserve the use or uses aforesaid, if a lawful and just use, *shall be deemed and adjudged to be appropriated.*

Those who know anything about the difficulties which beset engineers in the measurement of water can realize how difficult, if not impossible, it was for farmers having no knowledge of hydraulics to make a correct estimate of the volume they had actually diverted and used, and that it was impossible for them to make an accurate

claim for the volume they proposed to use. A law which would give to each irrigator all he claimed would be an absurdity, if every claim was known to be limited to the claimant's estimate of his actual needs, because of the difference in the capacity of claimants to make a just or accurate estimate; but a law which throws the door open to speculative claims and declares that a speculative absorber of streams can secure an adjudicated right thereto simply by asking for it is an iniquity. The Territorial water law was not framed for that purpose, but it nevertheless opened the door for the water grabber.

Thirty-one claimants to the water of Crazy Woman Creek filed these statements, some being for existing ditches and some for proposed ones. It does not appear from their character that there was any attempt to secure speculative rights, since some of the claimants asked for more water than they needed and others for less. The truth seems to be that the intention of all these irrigators was to comply with the requirements of the law in good faith, but that the volumes claimed had to them no definite meaning, and their statement was entirely unintelligible. There was probably not a farmer along the stream who knew whether he used 1 cubic foot of water or 10. Hence these claims exhibit chiefly the irrigators' lack of knowledge and the necessity, in an adjudication, of some impartial and adequate investigation of the facts on which any reasonable or just right should rest. It was the belief of the holders of these water rights, however, that the filing of this ex parte statement constituted in itself an absolute title to water, and that the further action in adjudicating these rights was only to confirm their title to the volume claimed. The outcome was in accordance with this belief. A comparison of the statements of claims filed in the county clerk's office with the volumes allotted in the decree shows that in nearly every instance they are the same. While a number of those who filed statements of claim do not appear in the decree, and a number of appropriators appear in the decree who did not file claims, there are enough appearing in both to show that the adjudication was almost if not entirely a proceeding to give the makers of these claims all they asked. The following table shows the agreement between the claims filed in 1886 and the appropriations established by the decree of 1889:

Comparison of appropriations under decree of 1889 with original claims filed.

Priority number.	Name of ditch.	Name of appropriator.	Volume allotted in decree, in cubic feet per second.	Volume claimed in statement.
2	John R. Smith	John R. and Agnes Smith	67.03	*a* 80
3	North Fork	Wyoming Land and Cattle Co.	30	55
4	Harris No. 1	W. Harris	12.2	12.2
6	Holt	Wyoming Land and Cattle Co.	8.20	8.20
8	Moreton	Moreton Frewen	22.32	22.32
9	Cook	Orrin Cook et al	33.55	33.55
10	North Fork of Crazy Woman.	J. A. Dowlin	28	28
17	Dick	Powder River Cattle Co	12.32	12.32
16	Kennedy	R. Kennedy et al	32	32
19	Blue Gap	Little North Fork Ditch Co.	26.5	26.5
19½	Teddy Miller	F. G. S. Hesse	84.45	84.45
20	Fort Collins	Fort Collins Land and Improvement Co.	210	210
21	Devoe No. 1	H. W. and C. M. Devoe	60.10	43
22	Devoe No. 2	do	78.11	78.11
25	Thompson & Matthews.	F. S. and G. F. Thompson	12	12
26	Mitchell & Long	B. Long and M. F. Mitchell	25	25
27	Harris No. 2	W. Harris	10	10

a 80 originally; 67.03 later.

If this creek carried enough water for all users, giving each appropriator all he claimed, the decree might not have been open to objection. Unfortunately the stream does not. It may for a few days or few hours each year carry 900 second-feet, although this is to be doubted; but during the latter half of the irrigation season the mean discharge is not one-tenth of this amount, and at times the channel below these ditches is a bed of dry sand. Not one-half the acreage designated in these appropriations has ever been irrigated, nor is there water enough in the stream to irrigate one-half of it without resorting to storage. With storage and with proper economy in the use of water all the land could probably be brought under cultivation, but to secure these there must be some method of restricting appropriators to their actual needs in the first place and some security for the control of stored water in the second. Extravagant appropriation is a prolific source of mischief in preventing both of these desirable results. The holder of a large appropriation claims the

right to control it whether he needs it or not. Parties hesitate to construct storage works to impound water which runs to waste when the title thereto is clouded, as it must be when more water than the stream carries at flood time is decreed to be appropriated.

These excessive rights have been an incessant source of trouble to the water commissioner. The holder of priority No. 2 can close all the ditches above him if his claim is recognized, and if it is not he has a grievance against the commissioner. Two instances have already occurred in which the assistance of the State engineer had to be asked to settle controversies over the right of these holders of a surplus to arbitrarily close the head gates of later appropriators. There is the further danger that these holders of extravagant rights will in time proceed to sell the surplus. If they have the right to do this, as the supreme court of the State has decided in a similar case, the time will come when the owners of the first three appropriations will practically control the stream, and the subsequent rights will not be worth considering. Meantime the water commissioner is forced to be judge, jury, and sheriff in the division of water among users. Under the limitation of the decree which gives to appropriators only the water needed, the commissioner refuses to close the head gates of subsequent appropriators, except in cases of actual need on the part of the holders of prior rights. But this policy is being continually called in question and could be carried out equally well without a decree.

DISTRICT 3.

This district, as shown in fig. 1, includes Clear Creek and its tributaries, and extends from the summit of Cloud Peak on the west to the junction of Clear Creek and Powder River on the east. It is one of the most important districts in the State and one of the most interesting to the student of water-right problems.

FLOW OF CLEAR CREEK.

Measurements of the amount of water flowing in Clear Creek were begun in 1889, their necessity having arisen from controversies over the water rights which the shortage of that year rendered acute. The location of the gaging station is about 4 miles above the city of Buffalo, as shown on fig. 2. The principal diversions above the gaging station are those in the mountains where two ditches carry water across a low divide into the head of French Creek. The measurements made at this point, therefore, do not represent the total flow of the stream, except at such times as the principal ditches are closed. The results of the measurements up to and including 1893 are not available; those for 1894 are shown diagrammatically on page xxxiii of the Second Biennial Report of the State Engineer of Wyoming and are given in the following table. During 1895 observations were

not made because it was impracticable to obtain the services of an observer. The results of the record for 1896 are published in Part

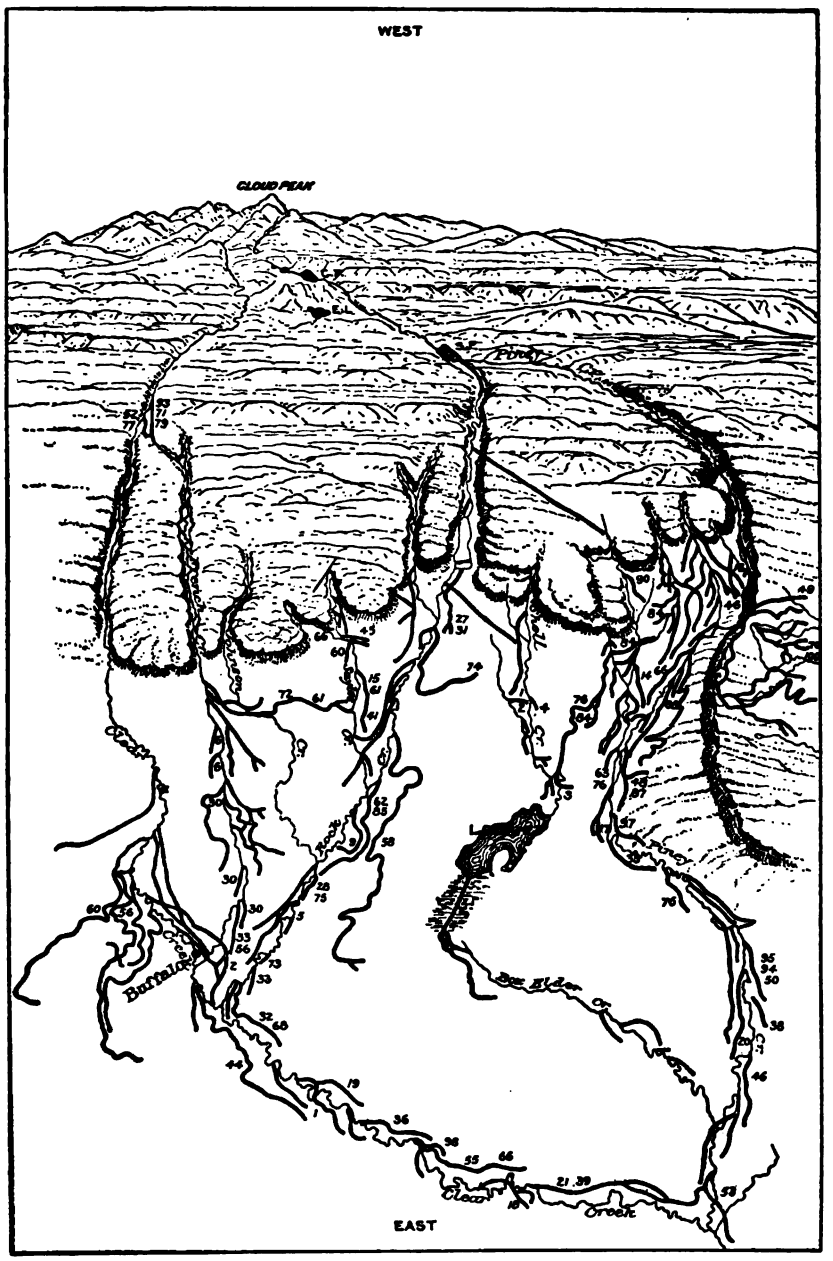


FIG. 2.—Irrigation systems on Clear Creek and tributaries.

IV of the Eighteenth Annual Report of the United States Geological Survey, on page 140, and those for 1897 in Part IV of the Nineteenth

Annual Report, of the Geological Survey, on page 298. The discharge for the three years is also given below and is shown diagrammatically in fig. 3 (page 31).

Estimated monthly discharge of Clear Creek at Buffalo, Wyoming.

[Drainage area, 118 square miles.]

Month.	Discharge.			Total.	Run-off.	
	Maximum.	Minimum.	Mean.		Depth.	Per square mile.
1894.	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*	*Acre-feet.*	*Inches.*	*Sec.-feet.*
June	853	168	283	16,841	2.68	2.40
July	242	62	148	9,100	1.44	1.25
August	80	46	54	3,320	.53	.46
September	80	46	55	3,273	.53	.47
1896.						
May	406	64	139	8,547	1.36	1.18
June	504	82	251	14,936	2.37	2.13
July	323	64	115	7,071	1.12	.97
August	134	40	66	4,058	.64	.56
September	56	40	46	2,737	.44	.39
October 8–19	38	29	32	756	.12	.27
1897.						
May	632	209	345	21,214	3.37	2.92
June	657	189	280	16,662	2.64	2.37
July	246	55	112	6,887	1.09	.95
August	82	39	54	3,320	.53	.46
September	.....	.....	*a* 30	1,785	.28	.25
October	.....	.....	*a* 30	1,845	.29	.25
November	.....	.....	*a* 30	1,785	.28	.25
December	.....	.....	*a* 26	1,599	.25	.22

a Approximate.

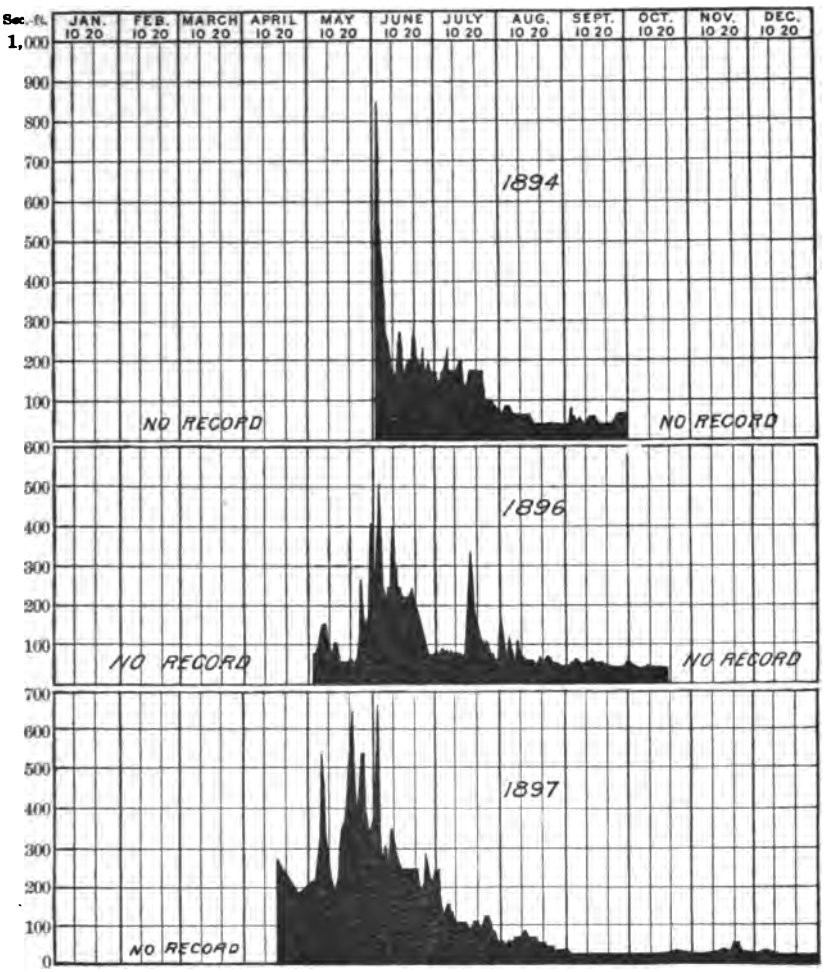


FIG. 3.—Discharge of Clear Creek near Buffalo, Wyoming, 1894, 1896, and 1897.

EARLY RIGHTS AND THEIR ADJUDICATION.

In May, 1878, Manlius Redmond began a ditch to water land along the main stream. It was, so far as the records show, the first attempt at irrigation in northern Wyoming, and the only attempt made that year. Ditches were built in 1879 along nearly every water course of the Bighorn Range, but in the previous year Mr. Redmond was alone. For more than ten years the building of ditches and the extension of the irrigated area made rapid progress, but 1889 was a season of drought, and the shortage on Clear Creek was so marked as to warn the users of water that the limit of profitable reclamation without the aid of reservoirs had about been reached. It also showed the need of an early determination of priorities. In the absence of this, position was everything; the ditch farthest upstream took its full supply

regardless of the rights or necessities of users below, while those farthest down got nothing.

Among the worst sufferers from this condition of affairs was the city of Buffalo. Two large canals, shown in fig. 2, had been built to carry the water of the North Fork of Clear Creek across a divide into French Creek. Their combined capacity was sufficient to drain the stream, and as no seepage returned, the loss to users below was absolute. An adjudication of priorities was begun before the close of the year, but before the preliminary steps had been completed the Territory of Wyoming held a constitutional convention and adopted a provision placing the control of the public waters of the State in the hands of the board of control. The judge of the district court ruled that this action divested his court of jurisdiction, and further progress was stayed until after the admission of Wyoming to statehood and the passage of the State irrigation law.

Under the State law rights to water are determined by the board of control, and an adjudication was begun by measuring the ditches which take water from a stream and by making surveys of the land irrigated or which can be irrigated. The measurements and surveys of Clear Creek and its tributaries were begun in 1891; when completed they were placed in the hands of W. J. Clarke, the division superintendent, whose duty it was to take the testimony of appropriators. Mr. Clarke at once began the taking of testimony, but had not completed this when the board of control met, in February, 1892. On his return from this meeting the division superintendent, who was a stockman, became involved in the "invasion" of Johnson County, as it was called, and all the proofs submitted were lost. It was necessary, therefore, to begin proceedings anew and to take all the testimony over again. Before this work was completed the testimony formerly taken was recovered, and both sets of proofs were before the board of control at its final determination of these rights. The two sets of proofs disclosed many discrepancies and contradictions, and were the cause of several contests, which delayed the final determination of these rights until 1895.

DIVERSION ACROSS DIVIDES.

The map of Clear Creek and its tributaries (fig. 2), shows the location and priority numbers of the several ditches; it also shows that one of these tributaries, Piney Creek, drains a larger mountain area than the main stream and also has a greater discharge. In addition there are the smaller tributaries of French, Johnson, Sayles, Rock, Shell, J. A., Boxelder, Bear Gulch, and Little Piney creeks. Clear Creek and Piney Creek each reach to the summit of the range and drain the entire eastern slope of Cloud Peak, its highest elevation. The other streams are cut off from the perpetual snows and only drain the outlying foothills; hence, while they have an abun-

PINEY CREEK BELOW OUTLET OF CLOUD PEAK LAKE.

dant supply for early irrigation, the late supply is wholly inadequate and, unless reenforced, will only serve for the reclamation of a restricted area. These smaller tributaries are, however, bordered by lands equal in area and of equal value with those along the valleys of the larger ones; hence some method of reenforcing their water supply became an early and important problem. The topography of this region offers unusual opportunities for doing this.

The head waters of French Creek are almost directly below Clear Creek, as its torrential flood comes from the rocky, snow-clad slopes of Cloud Peak. About all that is needed to turn Clear Creek out of its channel is a dam high enough to cause the water to overflow its bank, as the slope is toward French Creek from near its northern margin. One canal built to turn water into French Creek is only half a mile long, while the other, in a less desirable location, is only a mile in length. The map of Clear Creek and its tributaries (fig. 2) shows the location of these two canals, together with the priority numbers 71, 79, and 93 of their appropriations.

The turning of the water from Clear Creek into French Creek and the use of the channel of French Creek as a part of two canal systems created some perplexing problems for the board to solve in the determination of the two classes of rights from the latter stream. Both before and after the construction of the canals to provide this supplemental supply, parties had built ditches and appropriated the original or natural flow of French Creek. Some of these appropriators are interested in the canals in order to obtain an augmented supply, so that in a few cases the same individuals claimed rights to water from two sources through the same ditch to be used to irrigate substantially the same land. Other parties who made no claim to the natural flow of French Creek, but who were part owners in the canals to furnish the augmented supply, had built ditches from French Creek for the purpose of taking out the water turned into it.

There are, therefore, three classes of appropriators along French Creek. First, those who claim the natural flow of the stream; second, those who claim a right to the water of both Clear Creek and French Creek; and third, those who claim the right to use the channel of French Creek as a part of their ditch system, but draw their water supply entirely from Clear Creek. Among these different appropriators a difference of opinion exists as to the volume of water supplied by the natural flow of French Creek. At the time of the adjudication it was urged by the owners of the rights from Clear Creek that the claims of appropriators from French Creek were for more water than the creek carried, that the acreage originally irrigated had been extended by the unauthorized use of a part of the supply turned in, and that the board should restrict these claims. This was not done, because it was found impracticable to measure the flow of French Creek. To have done this would have involved shutting down the

ditches from Clear Creek and the ditches of appropriators above some of the tributaries of French Creek. A single measurement would not be sufficient. In fact, it would take a large number of measurements to reach any definite conclusion.

The demands of the area now under irrigation along the stream are so largely in excess of the natural flow of French Creek that to turn off the water from Clear Creek for a sufficient length of time to permit the measurement of the natural flow of French Creek would have caused the destruction of two-thirds of the crops along the stream. Those appropriators who have an interest in Clear Creek alone or in both supplies naturally objected to such action. The board was therefore compelled to rely on the engineer's surveys and on the proof submitted. Rights were restricted to the actual areas irrigated, but the source of the appropriation recognized was based on statements of irrigators. Those who claimed that their lands were irrigated from French Creek alone were given appropriations for their lands from that source, and those who claimed to have used only the water of Clear Creek were given a right from that stream. Whether or not this was in accordance with the facts will probably never be definitely known. It is one of the instances where haphazard development has reached a stage that renders any accurate settlement out of the question.

The same difficulty now confronts the water commissioner in performing his duties. The two ditches which divert Clear Creek into French Creek are so inaccessible as to make their frequent regulation impossible. Both are mountain ditches with head gates over 9,000 feet above sea level. Their channels are cut among the pines that cover this region and through the rocks from which they spring. To reach them requires a steep and toilsome journey of 15 miles from the mountain's base. They are at an elevation where frost is perpetual and snow almost so. The regulation of such ditches is, therefore, difficult and expensive, and any continuous measurement of the volume they carry is, for the present, out of the question, but the increasing value of these rights will in time render the accurate division of water indispensable. The water from Clear Creek mingles with the natural flow of French Creek until it reaches the first ditches built to divert it. There a part is taken out and carried over the divide between French Creek and Johnson Creek, and serves to reenforce the latter; the ditch is also extended across a second divide, where the remainder is turned into Sayles Creek to reenforce the flow of this stream and of Rock Creek below their junction.

The fluctuations in the flows of French Creek and Clear Creek do not agree, because the latter is fed from the summit of the range, while the former drains a larger area of the foothills region; it rises earlier in the season and also begins to subside earlier, but as the water turned in joins it near its source no measurements to deter-

A.

B.

RESERVOIR SITES ON PINEY CREEK.

A, At Elk Lake; *B*, At Mead Lake.

mine these variations can be had without an outlay greater than can now be afforded. The practical result is that during the early part of the season all users take from the natural flow of French Creek, while during the latter part nearly all are supplied from Clear Creek. The same conditions exist on Johnson and Sayles creeks, while on Rock Creek there is a third element of uncertainty. This, however, has arisen since the adjudication of rights, and will be described later.

PRAIRIE DOG CREEK.

Referring again to the drainage map of this district (fig. 2), it will be noticed that Piney Creek, which rises in the lakes on the northern

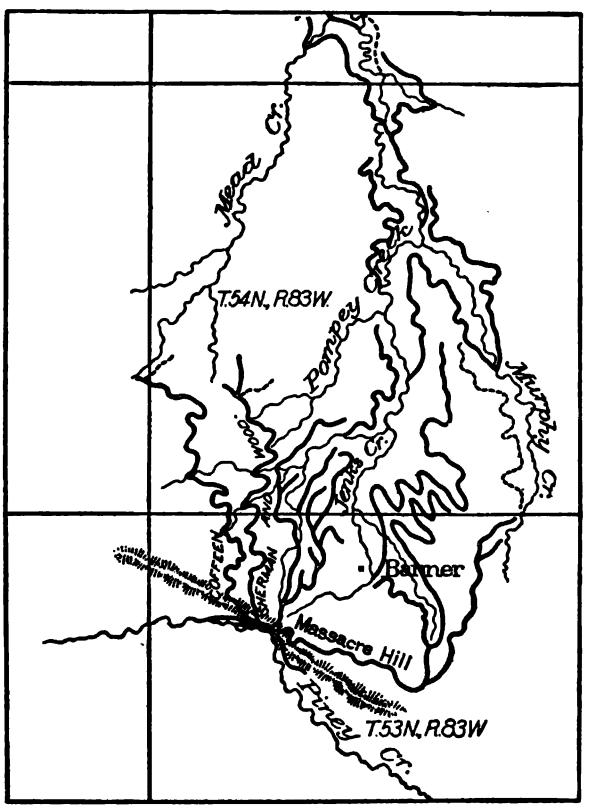


FIG. 4.—Ditches diverting water from Piney Creek across Massacre Hill divide to Prairie Dog Creek.

slope of Cloud Peak (Pl. II), not only drains a large extent of the summit of the range, but effectually cuts off a number of the smaller tributaries of Clear Creek therefrom. Piney Creek, like Clear Creek, receives nearly all its water from one direction. After the stream turns to the north the drainage on the east is into the smaller streams which rise in the foothills below. The most interesting peculiarity of the topography of this stream is, however, the fact that it does

not leave the mountain in a valley, but on a ridge, the mouth of the canyon of Piney Creek being near the summit of the divide which separates the drainage of Tongue and Powder rivers. This divide is an elevated spur of the main range known as Massacre Hill. It leaves the mountain almost at a right angle and extends for a considerable distance eastward. At one point Piney Creek is within 50 feet of its summit. After that it tumbles down into the valley which borders its eastern slope.

Mead, Pompey, Jenks, and Murphy creeks, which form Prairie Dog Creek, a tributary of Powder River, rise on the northern slope of Massacre Hill almost directly opposite the point where Piney Creek so nearly approaches its summit, as shown in fig. 2. Originally this stream was of little importance. It lacked the snowfall necessary to a perennial water supply, and although a few springs are found along its channel, the volume available for irrigation was insignificant. It was an easy project, however, to carry water from Piney Creek over the divide, as shown in fig. 4 and in Pl. IV, and turn it into this stream. Three ditches have been built for this purpose. These ditches follow the prevailing practice of this region in making natural channels a part of the ditch system. The owners of one ditch live along Prairie Dog Creek for 15 miles. The water turned in at the head is taken out by small ditches which divert the creek near their farms. There are 84 appropriations through the ditch of the Prairie Dog Water Supply Company which are diverted from the second stream through a score of smaller ditches.

Before the supplemental water supply had been provided a number of settlers filed on land along Prairie Dog Creek and built ditches therefrom. Some of these settlers became part owners of the ditch to provide an additional water supply; others did not, so that the board again had to deal with three kinds of rights from the same channel—rights to the natural flow, rights to the water turned in, and rights to both combined.

There was a further complication in this case. Prairie Dog Creek is a part of the drainage system of Tongue River, and if drainage lines had to be regarded, it belonged to that district; but since practically the entire water supply came from Piney Creek, the board ruled that water supply rather than the slope of the country should govern its supervision, and this portion of the drainage of Tongue River was made a part of the Clear Creek district.

SUMMARY OF RIGHTS TO WATER.

The diagrammatic map of the irrigation system from Clear Creek (fig. 2) gives the location of the ditches, with the priority numbers of their appropriations. A full list of these is given in the Third Biennial Report of the State Engineer of Wyoming, 1895–96, pages 181 to 194.

NORTH SLOPE OF MASSACRE HILL, ILLUSTRATING EROSION IN DITCHES FROM PINEY CREEK.

The amount of each of the appropriations was fixed by the acreage shown by the proof to have been irrigated, 1 cubic foot per second being allowed for each 70 acres. On Crazy Woman Creek it will be remembered the appropriations were based on the claims filed by appropriators, without regard to the actual use of the water. On French Creek appropriations were based on the areas reclaimed, without regard to the volume of water described in the original statement of claim. The relation of these claims to the actual use of water in irrigation is shown by the comparison of the volume claimed and the volume appropriated on French Creek, as given in the table below.

Volumes appropriated on French Creek as fixed by the order of the board of control and volumes claimed in appropriators' statements.

Priority number.	Name of ditch.	Name of appropriator.	Volume appropriated in decree, in cubic feet per second.	Volume claimed in original statement, in cubic feet per second.
1	Sneider No. 1	Mary L. Carpenter et al	1.64	8
2	Moeller No. 1	Alice S. Rapelyen	1.07	6
2	Moeller No. 2	do	.50	3
3	Moeller No. 3	do	4.28	13.97
4	John A. Fisher No. 1	John A. Fisher	.50	3.35
4	John A. Fisher No. 2	do	.43	23.15
4	Mayhew & Gorgen	Robert Foote	.17	12.40
5,7	Dundee	do	1.57	8.2
6	Gorgen	Peter Gorgen	.28	13.97
	Total		10.44	88.04

It will be seen from the totals that the appropriations established by reason of beneficial use amounted to only about one-tenth of those claimed. The ratio on all of the streams of this district could not be determined, because many of the claims were for the "unappropriated waters of the stream," designating no specific volume; but if these claims to whole streams were excluded, the claims for a definite volume alone were largely in excess of the actual use, as will be seen by the following comparison, in which all of the claims for indefinite amounts have been thrown out.

Volumes claimed and volumes actually used on streams in water district No. 3, in cubic feet per second.

Name of stream.	Volume used.	Volume claimed.
Total Clear Creek	232.78	853.6
Total Rock Creek	187.64	749.9
Total Sayles Creek	8.18	75.1
Total Johnson Creek	3.13	44.7
Total Piney Creek	334.88	943.8
Total Shell Creek	5.52	68.6
Grand total	772.13	2,735.7

ALLOWANCE FOR LOSS OF WATER IN TRANSMISSION.

Among the interesting questions raised in this adjudication was the extent of the loss of water from canals by seepage and evaporation and the authority of the board to provide for this by an increase in the appropriation.

In the original order of the board no such allowance was made, it being held that 1 cubic foot per second for each 70 acres is so much in excess of the requirements of crops, when the water is distributed with reasonable skill and economy, that it will provide for all necessary loss in transportation.

The Wyoming Land and Cattle Company was, however, dissatisfied with this decision, and on this and other grounds asked for and obtained a rehearing, at which measurements were presented showing the losses taking place between the head gate and the place of use.

The conditions on this ditch are somewhat unusual and need to be stated in order that the results may be properly interpreted. The head gate of the ditch is on what was formerly the Fort McKinney military reservation, near the mouth of the canyon and 3 miles above the town of Buffalo. At the time of these measurements, irrigation from the ditch or above the ditch was not permitted within the reservation limits. After crossing its boundary the ditch passes for several miles around and across a series of ridges on the slopes of which losses by seepage are considerable. In the ravines between these ridges and, in one place, along a slope which the ditch crosses there are beds of sand where the loss from percolation is so great that flumes have been built at these points. For 10 miles the following conditions favor an exceptional loss:

The land through which the ditch is built is not irrigated and local atmospheric conditions favor rapid evaporation.

It is the highest ditch and therefore gains nothing from the irrigation of lands above.

The arid land, the steep slopes, and the stretches of sand all add to the drain by percolation.

The measurements submitted were made in 1896 and 1897 by Fred Bond, a civil engineer of Buffalo, Wyoming, and were made in the following manner: A rectangular weir 4.75 feet in length was placed in the ditch immediately below the head gate, and a similar weir, with a length of 5.75 feet, was placed in the ditch near the lands to be irrigated, 10 miles from the first weir and 56 feet below it, that being the fall of the ditch in this distance. It was found by experiments that it took from eleven to thirteen hours for water to pass from one weir to the other. Hence in making these tests the measurements at the upper weir were taken in the morning and those at the lower weir in the evening, in order to measure as nearly as possible the same supply. The tables which follow give the results obtained, that for August 27 being evidently due to an error in measurement or to disturbance by storms.

Loss of water in transmission through ditch of Wyoming Land and Cattle Company.

Date.	Depth of water on upper weir, in feet.	Discharge, in cubic feet per second.	Depth of water on lower weir, in feet.	Discharge, in cubic feet per second.	Total leakage in flumes, in cubic feet per second.	Total loss, in cubic feet per second.	Loss, in per cent.
1896.							
July 10	0.88	11.448	0.56	7.865	(a)	3.583	31.3
July 11	.82	11.328	.55	7.642	(a)	3.686	32.6
July 13	.76	10.123	.55	7.642	(a)	2.481	24.5
August 25	.65	8.058	.50	6.876	(a)	1.182	14.7
August 27	.62	7.515	(?) .58	(?)9.270	(a)	-------	-------
August 28	.60	7.152	.46	5.877	(a)	1.275	17.9
August 29	.59	6.986	.45	5.671	(a)	1.315	18.9
August 30	.59	6.986	.44	5.547	(a)	1.439	20.6
August 31	.59	6.986	.45	5.671	(a)	1.315	18.9
September 1	.58	6.799	.44	5.547	(a)	1.252	18.5
1897.							
August 8	0.562	6.37	0.34	3.74	0.068	2.56	40.2
August 9	.567	6.69	.34	3.74	.09	2.86	42.8
August 10	.60	7.31	.36	4.06	.125	3.12	42.8
August 11	.68	8.59	.43	5.27	.08	3.24	37.7
August 12	.63	7.70	.38	4.42	.047	3.23	42.0
August 24	.467	5.99	.24	2.24	(a)	3.75	62.6

a Not measured.

It will be seen by examining these tables that the percentage of loss when a small volume of water was carried was much greater than when the depth was increased, seepage and evaporation being apparently about constant. If the board took the maximum loss of over 60 per cent as a basis for an order increasing the original right so as to give 1 second-foot for each 70 acres irrigated at the place of use, it would result in nearly double the original appropriation, while if the minimum loss of less than 15 per cent were made the basis of a new right, this action would require so slight a change as not to warrant a modification of the order.

The board refused to grant the additional allowance. The rehearing established a right to water for an additional acreage and increased the volume to be turned into the ditch. As the loss from seepage and evaporation seems about constant, and does not materially increase when the ditch is full, the larger the amount turned in the smaller the percentage of loss. Hence, with the larger right a minimum loss of less than 15 per cent may be expected.

Fort McKinney has since been abandoned and the reservation will soon be largely irrigated. It is believed that the percentage shown by the measurements will decrease in the future by the building of ditches above this one and the irrigation and saturation of the land below it.

The allowance of 1 second-foot to 70 acres being in excess of actual needs was regarded as sufficient to meet the average loss from the ditch at the present time and ample to meet the ultimate decrease.

The wide variation between percentages in the months when the use is heavy and in the later ones when the use is small, would make the establishment of a satisfactory or just appropriation to meet this loss difficult, if not impossible, while the probability of a progressive decrease in such loss would make it unwise to interfere. Even if the proportion allowed agreed with the conditions when made there is small likelihood of such agreement five years hence.

The board held, therefore, that the making of appropriations in excess of the statutory limit would not be approved; but that where satisfactory proof of unpreventable losses in transit made it apparent that the volume remaining, when the land was reached, would not produce crops, a temporary increase would be provided for by an administrative order to the water commissioner.

OWNERSHIP IN DITCH NOT NECESSARY TO THE ACQUIREMENT OF A WATER RIGHT.

One of the parties submitting proof of the beneficial use of water from Piney Creek was John Leitner, who showed to the satisfaction of the board that he had irrigated and reclaimed 15 acres of land through the Upper Phil Kearney ditch. The board by order estab-

lished the right to water for this land through said ditch. In his proof, Leitner stated that he was a part owner of the ditch through which the appropriation was made, and this claim was not contested in the proceedings before the board. Subsequent litigation arose over the ownership of the ditch, and the court decided that Leitner had no interest in it, but that Thomas J. Foster was the sole owner. Following this decision Foster requested the board of control to amend its records by making him the owner of the water right for 15 acres of land acquired by Leitner through the use of the water in its irrigation. Foster's request was based on the contention that his ownership of the ditch made him the owner of all the water it diverted or of all the rights to water acquired through it.

As it is the belief of the board that rights to water for irrigation, in the State of Wyoming, do not inhere either in the man who filed the claim or in the ditch which carried the water, but in the land reclaimed, the request for a transfer of the right from both the place where acquired and from the man who acquired it did not seem well founded; but recognizing the importance of the question involved, the board, before rendering a decision, asked the advice of the Attorney-General. The letter of inquiry and the reply were as follows:

CHEYENNE, WYO., *March 20, 1896.*

DEAR SIR: The State board of control is in receipt of a petition for review of the order determining the priorities of water from Piney Creek and tributaries, and requesting that the board of control cancel a certain certificate of appropriation of water to John Leitner, guardian, and find that Thomas J. Foster is the sole owner of the Upper Phil Kearney ditch.

The board of control has given careful consideration to this petition, and to the order of the court determining the ownership of the Upper Phil Kearney ditch, and has examined the evidence submitted before said board in the adjudication referred to. We find that the testimony submitted showed that Leitner had irrigated the land for which an appropriation was issued through the Upper Phil Kearney ditch and was entitled to an appropriation therefor, and after a reexamination of the evidence the board is of the opinion that the decree establishing this appropriation was correct.

In awarding an appropriation for the particular land for which an appropriation was claimed by said Leitner, the board did not attempt to determine that he had any ownership whatever in the ditch of Mr. Foster. It simply decided that the evidence submitted showed that the water had been transported through this ditch. The board has always held that its authority is restricted to the examination and determination of the facts showing the application of the water of the State to beneficial use and the rights thereby created, and that it could not determine the property rights in ditches through which the water was conducted. That question has been before the board repeatedly and the decisions have been uniform. In the same way the board is now of the opinion that it is not within its jurisdiction to say that Mr. Leitner is or is not a part owner in the Foster ditch. The decree of the court is regarded as determining that fact, but its validity or effect will not be in any way enhanced, in our opinion, by an assumption on the part of the board that it has authority to in any way determine such facts.

We have, by order, instructed the division superintendent to notify the water commissioner of the effect of the order of the court, and that the amount of the

appropriation through the Upper Phil Kearney ditch has been reduced by such order by the amount necessary for the irrigation of 15 acres, but we do not feel authorized to cancel the certificate of Mr. Leitner. We believe if he can secure satisfactory arrangements for the transportation of the water appropriated through the Upper Phil Kearney ditch by giving suitable compensation to Mr. Foster for the service rendered, or if he can make arrangements for the transportation of the water appropriated for this land through some other ditch, he has a perfect right under our laws to do so, and that the appropriation for the land is not destroyed by the fact that he is not part owner in a particular ditch.

Recognizing the importance of the questions raised, and desiring to avail ourselves of your assistance in their proper solution, we shall be pleased if you can advise us as to whether or not, in your judgment, the board has any authority whatever to determine or pass upon property rights in ditches, and whether or not the decree of the court in this case makes it mandatory upon us to cancel the certificate of appropriation of said Leitner.

Respectfully submitted.

ELWOOD MEAD,
President State Board of Control.

Hon. B. F. FOWLER,
Attorney-General, Cheyenne, Wyo.

MARCH 22, 1896.

DEAR SIR: Replying to your communication of March 20, with reference to the application of Thomas J. Foster for a review of your decision granting a certificate of appropriation to John Leitner, guardian, in which application for review Mr. Foster claims to be the sole owner of the Upper Phil Kearney ditch, and presents a decree of the district court of Johnson County, in an injunction suit brought by Mr. Foster against Mr. Leitner, the decree establishing the ownership of Mr. Foster:

I desire to state that while the State board of control was correct in respecting the decree to the extent of instructing your water commissioner that the amount of the appropriation for the Upper Phil Kearney ditch should be reduced by the amount of water granted therein to Mr. Leitner for the irrigation of fifteen acres, still at the same time you would not be justified in canceling the certificate issued to Mr. Leitner.

While there are allegations in the petition for review to the effect that Mr. Leitner made fraudulent representations to your board with regard to his having an interest in the ditch in question, still, in the absence of an affirmative showing of such fraud, there would certainly be no authority on the part of your board to take this for granted and cancel the certificate in question. The decree of the district court of Johnson County does not indicate this, nor do I understand that affidavits or other proof have been filed at this time for this purpose. The petition which is filed is not in the nature of a petition for rehearing, and I am of the opinion that this question can not be properly reached by your board in any other manner, and unless with the application for a rehearing proof should be presented to your office showing that at the time Mr. Leitner used the Phil Kearney ditch he did so as a trespasser and without the consent of Mr. Foster, then your certificate should stand.

As to whether or not Mr. Leitner is able to use the water in the future is certainly not a question to be considered, as under the statute he is given two years before he can be charged with abandonment, and if during that time he should build a new ditch or arrange with Mr. Foster or some other person to conduct the water from the stream in question upon his land, he would be entitled to appropriate enough to irrigate fifteen acres.

As to the claim that there is a cloud upon the title to Mr. Foster's ditch by your granting the certificate, this is certainly a mistake, and as Mr. Foster would not get the benefit of the water for the fifteen acres which is appropriated by Mr. Leitner, I can certainly see no advantage to Mr. Foster in securing the cancellation of the certificate in question.

Respectfully submitted.

BENJAMIN F. FOWLER,
Attorney-General.

Hon. ELWOOD MEAD,
State Engineer, Cheyenne, Wyo.

The reply confirmed the board's views and the request was refused, Mr. Leitner being given two years in which either to build a new ditch or to arrange with Mr. Foster for the transportation of the water to which he was entitled through the Upper Phil Kearney ditch.

DISTRICT 4.

This district, shown in figs. 1 and 5, includes Big Goose Creek and its tributaries. Little Goose Creek is by far the most important tributary, the acreage irrigated along its valley being greater than along the valley of the main stream. Among the smaller tributaries, Soldier, Rapid, and Beaver creeks are the principal branches of Big Goose Creek, while Jackson, Hanna, Tepe, Davis, Trabing, Kemp, Sackett, and Kruse creeks are all branches of Little Goose Creek, which aid in augmenting its flow and from which lands are irrigated. Here, as in the Clear Creek district, the principal stream drains the summit of the range and cuts off the late water supply of the smaller tributaries, and here also irrigators along these smaller tributaries have taken advantage of the topography of the country to relieve their shortage by carrying water across the divides. This transfer of water from one stream to another has been carried to such an extent in this district that some users get water from half a dozen sources. Irrigators near the lower end of Little Goose Creek have the natural flow of the stream, water from Piney Creek, and from three ditches from Big Goose Creek, making in all five separate sources of supply. These transfers from one watershed to another and this extended use of streams as parts of ditch systems have undoubtedly greatly extended the acreage of land reclaimed, but it has at the same time enormously increased the difficulty of determining and protecting rights. Determining the rights to one stream is hard enough, because of the uncertainty and conflicts of early records, but when these uncertainties embrace four or five sources the problem is infinitely more complex. Take as an illustration the rights to water through the Last Chance ditch. Its head gate is in Little Goose Creek. Whenever there is a surplus in this stream irrigators take from the nearest source. Whenever the supply is inadequate a ditch owned by the same persons diverting water from Big Goose Creek is opened and water is used from that stream. These irrigators have therefore established a right to water

from both streams. The question which confronted the board was, How to frame a decree which would give to these irrigators the right to take water from both streams and at the same time limit it to a single appropriation. If it was absolutely certain that water rights would remain attached to the land where acquired and the decree could have been so worded as simply to give this land whatever water was

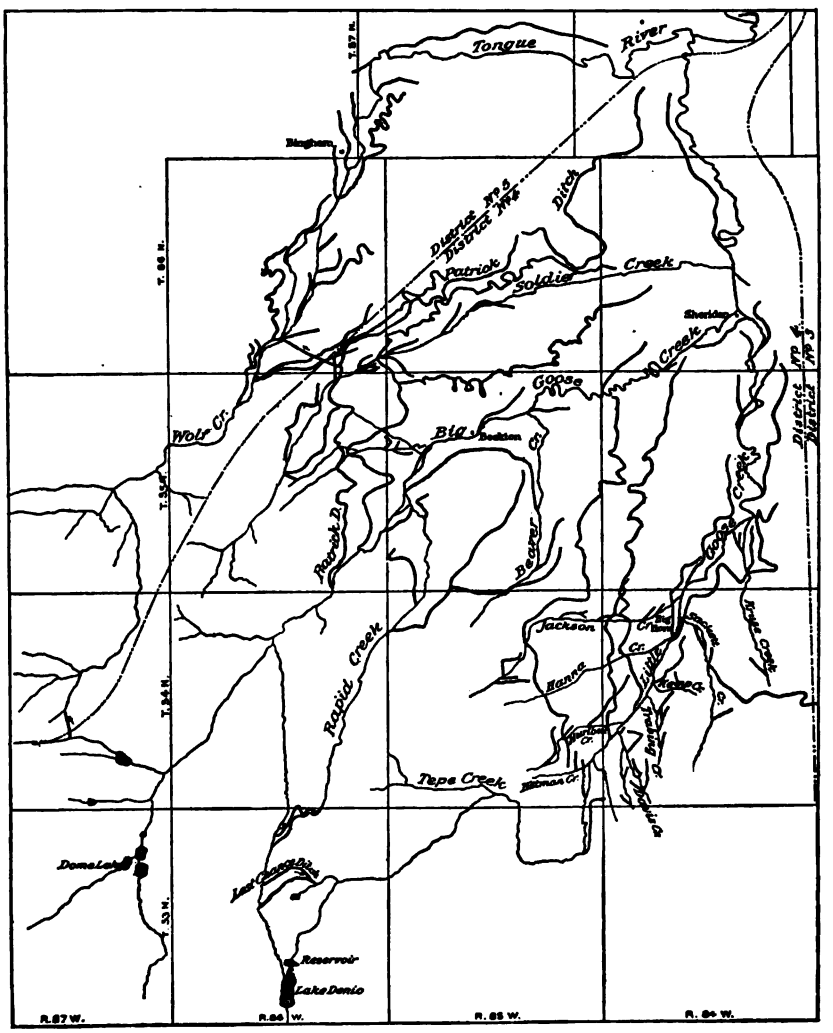


FIG. 5.—Location of ditches on tributaries of Tongue River, Division II, district 4.

needed, there would have been little trouble in preparing the certificates, but the statutes of Wyoming prescribe the form of certificates of appropriation and require the board issuing them to give the volume appropriated in cubic feet per second continuous flow. It was necessary to give the same number of second-feet from each stream, and to

TIMBER FLUME IN CANYON OF TONGUE RIVER.

make this continuous, since there is no authority in the law for limiting the appropriation to certain months or to certain portions of the irrigation season. The board endeavored, in framing its order, to prevent any claim to a double appropriation being set up in the future. But its success will largely depend upon the decision of the supreme court as to whether rights acquired under the Territorial law can be sold and transferred to other lands. If this right should be upheld, there is no question that the right to dispose of the appropriations from one of these streams will become a matter of litigation.

The use of two ditches to divert a single appropriation and the use of a natural stream as a part of the canal system made it difficult to fix priorities. Many of the ditches from Little Goose Creek were constructed prior to those which turn water from Big Goose Creek and have different priority numbers. Hence the same tract of land has a divided appropriation—the two parts coming from different sources and having different priorities.

The boundaries of district No. 4 are based on drainage lines, and prior to the beginning of irrigation there was no connection between the streams of this district and those on either side above the mouth of Big Goose Creek. There are three places at which water is transferred from one district to another. It is turned from the North Fork of Big Goose Creek into the head of Wolf Creek in water district No. 5, and by the Patrick ditch from Big Goose Creek across Soldier Creek, and thence into Wolf Creek at a point about 12 miles farther down; and on the south water is turned into Little Goose Creek by one of the canals from Piney Creek, so that drainage lines are being almost obliterated. When the Granger canal is completed there will be a continuous connection by ditches from Powder River on the south to the Montana boundary, a distance of 100 miles, uniting four districts. A summary of the appropriations of water in this district is given in the First Biennial Report of the State Engineer of Wyoming, 1891–92, pages xxv to xxx, and continued in the Third Biennial Report, 1895–96, pages 177 and 180.

DISTRICT 5.

In district No. 5, shown in figs. 1 and 6, the cost of ditches, rather than the adequacy of the water supply, governed the location of the farms first reclaimed. Tongue River, the main stream, has still a large volume unappropriated, which each year runs to waste, but on a number of its tributaries there are more lands under ditch than these streams will fertilize. This condition of affairs is due to the fact that ditch building from Tongue River is expensive, as shown in Pl. V. After the stream leaves the mountains the grade of its channel is very light and the valley narrow. On both sides are high bluffs with very little irrigable land along their slopes, while to reach the table-lands above requires long, crooked ditches with many dikes or flumes, where ravines or tributary streams have to be crossed.

The shortage of water on the tributaries led to early quarrels over its division. Litigation over water rights on Wolf (east of area shown on fig. 6), Amsden, Smith, and Hewes (or Columbus) creeks began when Wyoming was a Territory, but no conclusion had been reached when the State law went into effect. The testimony which had been taken in this litigation was transferred to the board of control, and these streams were among the first to be dealt with by that body. Since the priorities on these tributaries were earlier than the appro-

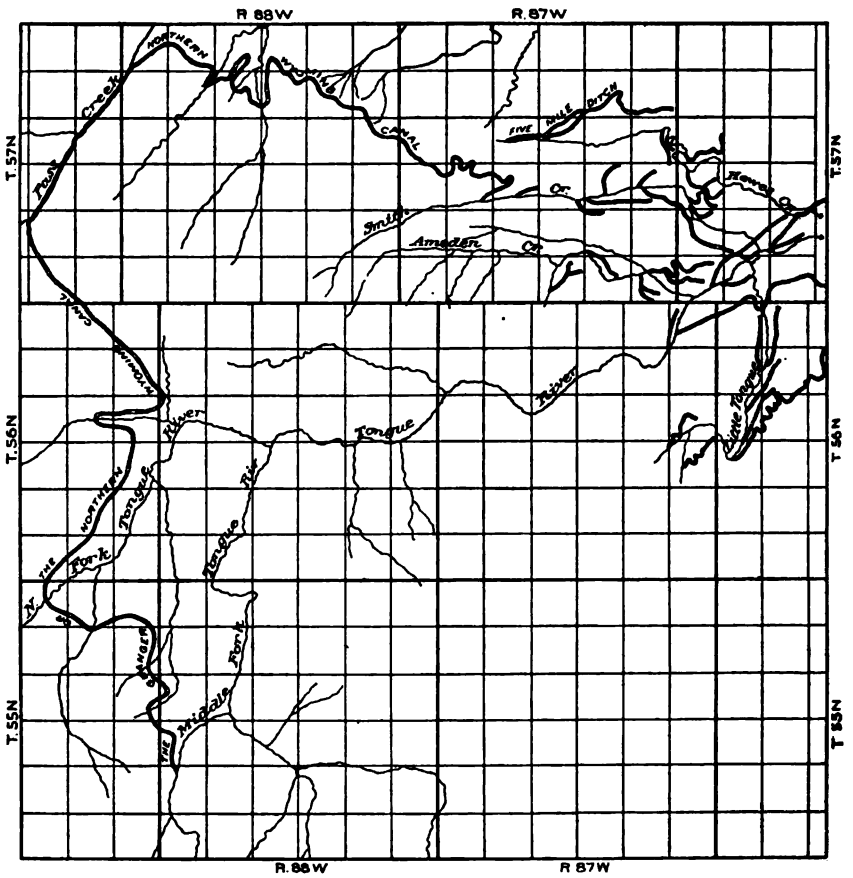


FIG. 6.—Location of ditches on North Fork of Tongue River, Division II, district 5.

priations on the main stream they were independent of any claims on the latter. Hence, in the final determination of these rights, the board of control dealt with each as a separate and distinct drainage basin. The announcement of the policy of the board of control, in limiting water rights to the volume actually used, was not in accord with the views of some of these claimants, who held that their statements of claims described the amounts of their appropriations, and that to reduce these was an encroachment on vested rights.

An appeal from the board's order was taken by the second appropriator from Amsden Creek. This appropriator was allowed 0.86 of a cubic foot per second for the irrigation of 60 acres of land, the location of the land being described. The appeal was based on the claim that water for 150 acres had been appropriated, and made it necessary for the court to rule on the question as to what, under the Wyoming law, constituted an appropriation. The following extract from the proof of appropriation gives the testimony on which the board limited the right to water for 60 acres:

Question. State the number of acres watered each subsequent year, and give the legal subdivisions on which the water is used.

Answer. Claimant increased the amount of land irrigated each year from 1882 to the present time, and now has about 60 acres under cultivation and irrigation.

Question. State the acreage said ditch is capable of watering, and show on a map or plat, on a scale of 2 inches to the mile, the location of said ditch and the land it is capable of watering.

Answer. One hundred and fifty acres.

REMARKS.—Claimant appropriated water sufficient for 150 acres of said land, and now claims water for said land. He does not use said water, has not heretofore, but if farming becomes more profitable he may desire to cultivate all of his land, and his appropriation was made to cover all of said land.

It will be seen from this testimony that only 60 acres had actually been watered, but that the claimant stated it was his intention at some future time, when irrigation became more remunerative, to water more land. The map made by the State engineer's office showed that about 100 acres of land belonging to the claimant could be watered, but that about 50 acres of land belonging to other parties could be watered from this ditch, so that the claim for a possible irrigation of 150 acres from the ditch was correct. The maps and proofs of other claimants showed that about 435 acres of land had been reclaimed, and the actual necessities of this land had more than exhausted the water carried by the stream, so that the resulting shortage had led to litigation over these rights prior to the admission of Wyoming to statehood. This lack of an adequate water supply was shown by the gagings made by the State engineer's office, the volume in July being 5.25 cubic feet per second, while the aggregate of the appropriations made by the board of control on the restricted basis of the necessities of the land reclaimed was 6.21 cubic feet per second. If the claim of an appropriation for 150 acres, instead of 60, had been recognized by the board, the water for the additional 90 acres would have been taken away from lands already reclaimed and from present users, to be held as a speculative property by this claimant until it became valuable enough for him to use, or until, trading on the necessities of those now using it, he could compel them to purchase it from him.

The evils of basing appropriations of water on such considerations would not have ended with this individual. If his belief that he would

at some future time require water enough for 150 acres of land constituted an appropriation, the belief of any appropriator on a stream that he might at some future time use more water would also have entitled him to the full amount of his probable necessities, and appropriations would be fixed not by physical conditions, but by the state of men's minds when filing claims. The first appropriation on this stream was for water sufficient to reclaim 100 acres, but the owners of that ditch had, prior to the adjudication, enlarged it, and had actually reclaimed 110 acres additional, for which they received at the hands of the board of control an appropriation having a later priority. If, however, the contention of the appealing appropriator had been sustained, the appropriator holding the first priority could have maintained that he had intended to appropriate the whole stream and have taken it, while the other five appropriators, including the party appealing from the board's decision, would have been compelled to look to him rather than to the mountains for their water supply.

It seems strange that such an indefinite and unreasonable basis for water rights should ever have had any defenders or received serious consideration; but until the court sustained the board's ruling public opinion in the State was very evenly divided as to the legality of the action. The reason for this lies in the fact that the evils of these extravagant grants are not at once manifest. The term "cubic foot per second" is, to the majority of irrigators, wholly meaningless, and this fact made them unable to appreciate either the effect of an allowance of their claims or the adequacy of the appropriation which the board of control had approved. When a claim had been made for 20, 50, or 100 second-feet of water, and the claimant found that it had been cut down to 1, 2, or 3 second-feet, it was but natural that he should feel aggrieved and be inclined to look with distrust on the assurance that this volume was entirely sufficient to meet all his requirements. The result of basing appropriations on the volumes claimed from Amsden, Smith, and Hewes creeks is not, however, a matter of speculation.

On the last-named stream twenty-eight parties submitted proofs of appropriations, and the surveys of the engineer's office showed that each of them had used water. The aggregate volume of the appropriations approved by the board was 34.8 second-feet, which was less than half the 76 second-feet claimed by the first five. Subsequent experience has shown that the volume fixed by the board's order is more than the stream will furnish, and some of the later appropriators are now building a ditch from Tongue River; but if the stream does not carry 34 second-feet it certainly would not have supplied 76 second-feet, and the allotment of this volume to the first five appropriators would have left nothing for the remaining twenty-three. It is manifest, also, that they have never used more than the stream carries, and of course it is impossible to acquire an appropriation

without ever having diverted or used the water. The injustice of making these claims the foundation of adjudicated rights is strikingly shown in the case of this stream. The claim of the first appropriator was for 21 second-feet, and of the second for 10 second-feet, so that if these two had been given all they asked they would practically have owned the stream.

Smith Creek did not supply enough water to meet the actual needs of users when the priorities were determined. The order of the board limited the rights of all the appropriators to 13.97 cubic feet per second. This was probably in excess of the volume actually used, but it was a great reduction from what was claimed, since that of the first appropriator alone was for 150 second-feet, or more than ten times the volume which the stream carries. The claimant of 150 second-feet received 6 feet, and was indignant because he believed that he had been unjustly deprived of the difference.

LITTLE TONGUE RIVER.

The rights to water from Little Tongue River, the principal tributary of Tongue River, have not as yet been determined. At the time of the adjudication there had not been a sufficiently thorough investigation of the physical conditions to enable the board to reach a satisfactory conclusion as to the merits of some of the questions which must be decided. One of these is a physical problem of great interest. It is a well-known fact that all of the streams draining the eastern slope of the Bighorn Mountains lose more or less water through underground channels. One of the branches of Powder River sinks, to reappear below with diminished volume. The losses on the South Fork of Clear Creek amount to a considerable percentage of its entire flow during the latter part of the irrigation season, and a ditch built to turn water therefrom into Crazy Woman Creek has been a failure, because the water diverted disappeared. But of all these streams the loss in Little Tongue River is the greatest.

During an examination made five years ago a number of funnel-shaped openings were discovered, through which large volumes of water were disappearing, with no evidence of their reappearance. In one case the volume was measured and was found to be in excess of 3 cubic feet per second. In the places examined the water sinks where streams cut across the upturned edges of a limestone stratum of great thickness. Whether the total volume lost from Little Tongue River is greater than that from the main stream is as yet unknown, but the percentage is greater and the loss more apparent. Those dependent on the stream have made many efforts to ascertain the location of these underground channels and close them up, and much has been accomplished in this direction. One of the parties engaged in this work claims that the water thus saved should not be subject to the rights of appropriators of the normal discharge, but

should be wholly independent thereof. In his claim for a separate right and for its adjudication apart from the rights on the main stream he sets forth by affidavit the facts on which the claim is based. The affidavit is here given:

John R. Gatewood, being first duly sworn, deposes and says that he is a citizen of the county and State aforesaid; that he is the person described in the annexed "Application for a permit to divert and appropriate the waters of the State of Wyoming," and that the water which he desires to appropriate from the South Fork of the Tongue River, one of the natural streams of the State, is water which has not as yet been appropriated by any person for "beneficial uses;" that in the said South Fork of Tongue River, back in the mountains, at places described in said "application," there are natural holes on the bottom of the stream through which about 20 per cent of the natural flow of said water, at low water, escapes into the earth, and that, as far as affiant has been able to ascertain, does not again run into said stream or any other natural stream, but is wholly lost; that said affiant believes that he can save said water for beneficial uses; that he is the owner of possessory rights to agricultural lands in said county, and has not water to reclaim the same, and that by being allowed to save this water he verily believed, and does believe, that he can secure said water for said beneficial uses.

A list of the adjudicated rights in water district No. 5 is given in the First Biennial Report of the State Engineer of Wyoming, 1891–92, pages xxxiii to xxxvi and pages xxiii and xxiv. These tables are continued in the Third Biennial Report, 1895–96, page 176.

APPROPRIATIONS IN DIVISION III.

On the west side of the range but little has been done by the State irrigation authorities. Rights have been determined in the sixth district, but not in the fourth and seventh (see fig. 1), there being so large a surplus as to obviate any controversy among users.

DISTRICT 6.

The following order and tabulation gives the rights established in the sixth district and the form in which the entry of the board's action is made in the records of the board of control:

ORDER ESTABLISHING PRIORITIES AND AMOUNTS OF APPROPRIATIONS OF WATER FROM NO WOOD RIVER AND ITS TRIBUTARIES.

In the matter of the determination of the rights of appropriators of water from No Wood River and tributaries, in water division No. 3, Bighorn County, Wyoming.

In this matter the board of control having heretofore, at its regular meeting held on the 21st day of March, 1896, duly made and entered an order for the adjudication and determination of the rights to the use of the waters of No Wood River and its tributaries, in water division No. 3, and directing the State engineer to proceed as soon as possible and survey and measure all the ditches diverting water therefrom;

And it appearing that the State engineer, in pursuance of said order, after giving due and legal notice according to law to all appropriators from said stream and its tributaries, did survey and measure all the said ditches, and prepared and filed complete maps and a report in the office of the said board:

Thereafter N. H. Brown, superintendent of said water division No. 3, after due

and legal notice to appropriators of water fixing the time and place of receiving proof of appropriation from said stream and its tributaries, did appear at the time and place fixed, and did take and receive the sworn proofs and testimony in writing of all persons appearing and claiming rights to water in said stream, and thereafter exposed said proof to public inspection on a day fixed according to law, and said proofs having been examined and no contests having been instituted were thereafter duly filed, with his report and findings, in the office of said board;

And now this matter coming regularly on for hearing and determination by the board of control, upon the records in the State engineer's office and the proofs of appropriation duly taken and submitted by said superintendent, and upon the maps and report of surveys and measurements of streams and ditches duly made by the State engineer and his assistants, and the board having now examined the records in the State engineer's office, the proofs of the beneficial use of water, filed in the office of said board, and having read the report and tabulation and heard and considered the recommendations of said N. H. Brown, superintendent of said division No. 3, that certificates of appropriation be issued, and the board, being now fully advised, finds as follows:

FINDINGS.

The board finds that the appropriations of water determined and established by this order were made from the following-named streams:

No Wood River proper and Bear Creek, Boxelder, Upper or Little Canyon Creek, Crooked Creek, Otter Creek, Spring Creek, Tensleep Creek, Broken Back Creek, Alkali Springs Creek, Paint Rock Creek, all tributaries of No Wood proper.

Cherry Creek, tributary of Boxelder.

North Fork Spring Creek, tributary Spring Creek.

Lower Canyon Creek, tributary Tensleep.

North Fork Broken Back, tributary Broken Back.

Buffalo Flat Creek, tributary Alkali.

Medicine Lodge Creek, tributary Paint Rock.

Coon Holler or Coon Creek, tributary Spring.

That in order to adjudicate and establish the rights of the various appropriators from these several streams it is necessary, in addition to the determination of the order of priority and general priority number of each of the rights to water from No Wood and its tributaries, taken as a whole, for the board to determine and establish the priorities of right growing out of appropriations from each of said streams as between the appropriators therefrom themselves.

The board finds that the rights of appropriators from each of the various tributaries are subject to the rights of prior appropriators on the main stream below, or on the stream into which said tributary flows, and to these rights only.

Subject to the foregoing limitations and conditions, the board finds the name of the appropriators, the priority numbers of said appropriations, the maximum amounts thereof, the uses for which the water was appropriated, and the legal subdivisions of land on which the water appropriated is to be used and to which it is attached are as set forth in the following table.

ORDER.

It is therefore ordered by the board of control that each of the following-named appropriators from No Wood and its tributaries above named do have the use of the water of the stream from which said appropriation was made by him, or them, for the beneficial purpose for which acquired and for no other, and that the names of the appropriators, the priority number of each of said appropriations, the maximum amounts thereof, the names of the ditches or other diverting works through which the appropriation is made, the dates of said appropriations, the beneficial use to which the water is appropriated, and, when for irrigation, the description

of the land to which the water appropriated is attached, shall be the same as stated in the following table under its appropriate heading, which said table is hereby made a part of this order.

It is further ordered that each of the appropriations for irrigation shall be sufficient for the economical irrigation of the land described and no other, not to exceed 1 cubic foot of water per second of time for each 70 acres irrigated.

NO WOOD RIVER PROPER.

Priority number.a		Name of ditch.	Name of appropriator.	Post-office address.	Date of appropriation.	Use to which water is applied.	Amount appropriated, in cubic feet, per second.	Number of acres irrigated.
5	1	S. V	John D. Gill	Redbank, Wyo.	May 1, 1885	Irrigation	0.79	55
11	2	Cornell No. 1	Enoch Cornell	do	Apr. 2, 1886	do	.90	20
12	3	Mead No. 1	John Mead	do	May 1, 1886	do	.15	10
38	4	Spratt	Thos. Spratt	Bonanza, Wyo.	May 13, 1889	do	3.21	225
41	5	Green Spot	Chas. Mills	Redbank, Wyo.	1889	do	.15	10
41	5	Cornell No. 2	Enoch Cornell	do	1889	do	.12	8
42	6	Suez	Taylor Bros	Bonanza, Wyo.	Mar. 15, 1890	do	1.86	130
43	7	Harmony	O. C. Morgan	do	Mar. 20, 1890	do	2.28	160
43	7	do	Henry Jordan	do	do	Domestic and irrigation.	.88	60
43	7	do	Louisa M. Smith	do	do	do	.21	15
43	7	do	A. G. Smith	do	do	do	.53	37
43	7	do	Jas. A. Quiner	do	do	do	.74	50
46	8	Umslopogaas No 2.	A. L. Coleman	Redbank, Wyo.	Nov. 1, 1890	do	.64	45
49	9	Western	L. J. Diehl	Bonanza, Wyo.	Aug. 2, 1892	do	2.78	195
49	9	do	Nich. Carstensen	Hyattville, Wyo.	do	do	1.14	80
49	9	do	Geo. A. Bell	do	do	do	4.08	286
53	10	Ilg	E. M. Ilg	Bonanza, Wyo.	Oct. 16, 1893	do	.71	50
53	10	do	Otto Ilg and Arthur A. Ilg.	do	do	do	.68	48
60	17	Avent	Ira M. Avent	do	July 5, 1895	do	1.71	120
62	18	Cornell No. 2, enlargement.	John Mead	Redbank, Wyo.	Sept. 16, 1895	do	.21	15
63	19	Harmony Mill enlargement.	Henry Jordan	Jordan, Wyo.	Jan. 4, 1896	Mechanical	1.15	.....

BOXELDER CREEK, TRIBUTARY OF NO WOOD RIVER.

1	1	Two Bar	Estate of Harvey Booth.	Redbank, Wyo.	Apr., 1884	Irrigation	0.57	40
16	2	Helms No. 1	Henry Helms	do	Apr., 1886	do	.40	28
21	3	Wells No. 1	Chas. Wells	do	May, 1887	do	.46	32
24	4	Wells No. 2	do	do	Sept. 1, 1887	do	.63	44
25	5	Helms No. 2	Henry Helms	do	Sept., 1887	do	.31	22

UPPER OR LITTLE CANYON CREEK, TRIBUTARY OF NO WOOD RIVER.

13	1	Red Bank	H. A. Richards	Redbank, Wyo.	June, 1886	Irrigation and stock.	4.57	320
40	2	Umslopogaas	A. L. Coleman	do	May, 1889	Irrigation	.50	35
45	3	Rosebud	Harvey Smith	do	Sept., 1890	do	.10	7
56	4	Hillside	C. S. Walu	do	Feb. 16, 1894	do	.93	65
55	4	do	Alex. Arledge	do	do	do	.50	35

CROOKED CREEK, TRIBUTARY OF NO WOOD RIVER.

8	1	F. D. Helmer, or Brunner No. 1.	Frank D. Helmer	Redbank, Wyo.	May 15, 1885	Irrigation	1	70
8	1	Ainsworth	F. S. Ainsworth	do	do	Irrigation and mechanical.	1.14	80

a The first number is the general priority number in reference to the rights to water from No Wood River and its tributaries taken as a whole; the second is the priority number in reference to the rights from each stream.

OTTER CREEK, TRIBUTARY OF NO WOOD RIVER.

Priority number.		Name of ditch.	Name of appropriator.	Post-office address.	Date of appropriation.	Use to which water is applied.	Amount appropriated, in cubic feet, per second.	Number of acres irrigated.
4	1	Grout	C. E. Shaw	Redbank, Wyo.	Apr. 1, 1885	Irrigation	1.05	78½
7	2	Dyson	do	do	May 10, 1885	do	.66	46½
28	3	Daly	do	do	1887	do	.54	38
31	4	Higbie	C. J. Higbie	do	May, 1888	do	2.51	176
58	5	Sawyer	George Sawyer	do	Nov. 7, 1894	do	.71	50

SPRING CREEK, TRIBUTARY OF NO WOOD RIVER.

5	1	Emge & Robinson No. 2.	Wm. Robinson	Redbank, Wyo.	May 1, 1885	Irrigation	0.43	30
5	1	Walu Bros	R. A. Walu	do	do	do	1.43	100
16	2	Emge & Robinson (Hollywood).	Wm. Robinson	Tensleep, Wyo.	1886	do	.43	30
17	3	Standish & Henderson.	Elmer Chatfield	do	Mar. 20, 1887	do	1.93	135
35	4	Tunnel	A. F. and L. Walu	do	Sept., 1888	do	2.86	200
52	5	Tunnel enlargement, No. 2.	R. A. Walu	do	Sept. 14, 1893	do	.36	25

TENSLEEP CREEK, TRIBUTARY OF NO WOOD RIVER.

2	1	Winn	Milo Burke	Tensleep, Wyo.	Sept. 1, 1884	Irrigation	2.43	160
7	2	Columbian	Milo Burke and Bessie C. Burke	do	May 10, 1885	do	3.00	210
10	3	Bay State No. 1	Bay State Cattle Co.	do	1885	do	1.57	110
22	4	Burke	Milo Burke	do	Aug. 1, 1887	do	.43	30
30	5	Perfection	Fred G. S. Heese	Buffalo, Wyo.	Apr. 10, 1888	do	7.14	500
44	6	Bay State No. 2	Bay State Cattle Co.	Tensleep, Wyo.	May, 1890	do	.43	30
48	7	Wyman	S. A. McLaughlin	do	July 2, 1892	do	1.14	80

BROKEN BACK CREEK, TRIBUTARY OF NO WOOD RIVER.

7	1	Carothers No. 2	Ed Carothers	Hyattville, Wyo.	May 10, 1885	Irrigation	.21	15
10	2	Cranky Jack	John D. Hopkins	Tensleep, Wyo.	1885	do	1	70
18	3	Hardscrabble	W. R. Williams	do	Mar. 25, 1887	do	.64	45
28	4	Carothers North Fork.	Ed Carothers	Hyattville, Wyo.	1887	do	.09	6
28	4	Carothers No. 1	do	do	1887	do	.36	25
28	4	Carothers No. 3	do	do	1887	do	.29	20
29	5	North Fork	John D. Hopkins	Tensleep, Wyo.	Apr. 1, 1888	do	.71	50
41	6	Dry Fork	H. E. Miller	do	1889	do	.08	5
47	7	Carothers No. 5	Ed Carothers	Hyattville, Wyo.	1890	do	.43	30
47	7	Carothers No. 6	do	do	1890	do	.08	5
47	7	Carothers North Fork No. 1.	do	do	1890	do	.06	4
57	8	Williams	W. R. Williams	Tensleep, Wyo.	July 10, 1894	do	.29	20

PAINT ROCK CREEK, TRIBUTARY OF NO WOOD RIVER.

6	1	Big Bear	David Matthews	Hyattville, Wyo.	May 2, 1885	Irrigation	.43	30
6	1	do	John Luman	do	do	do	1.14	80
14	2	Meyers	H. W. Meyers	do	Sept. 11, 1886	do	.96	67
14	2	do	John Weintz	do	do	do	.15	10
14	2	do	Lee Nansell	Bonanza, Wyo.	do	do	.86	60
19	3	Luman & Allen	John Luman	Hyattville, Wyo.	Apr. 8, 1887	do	.83	58
19	3	do	Jas. D. Allen	do	do	do	.89	62
23	4	Bernstein	Clara F. Collins	Basin, Wyo	Summer, 1887.	do	.86	60
27	5	Elk	Abraham Gotwals.	Hyattville, Wyo.	Fall, 1887	do	2.86	200

PAINT ROCK CREEK, TRIBUTARY OF NO WOOD RIVER—Continued.

Priority number.		Name of ditch.	Name of appropriator.	Post-office address.	Date of appropriation.	Use to which water is applied.	Amount appropriated, in cubic feet, per second.	Number of acres irrigated.
27	5	Elk	John Luman	Hyattville, Wyo.	Fall, 1887	Irrigation	2.64	185
27	5	do	Jas. D. Allen	do	do	do	1.43	100
28	6	Bernstein No. 1	Estate of Fred Bernstein, D. B. Stanton, agent.	Basin, Wyo	1887	do	5	350
33	7	Military	T. F. Nelson	Hyattville, Wyo.	May, 1888	do	.54	38
37	8	Go Ahead	Willis J. Booth	do	May 1, 1889	do	1.79	125
37	8	do	H. D. Hendricks	do	do	do	1.57	110
37	8	do	T. F. Nelson	do	do	do	.43	30
50	10	Shuck & Wilson	Zelotes Wilson	do	Mar. 20, 1893	do	.79	55
50	10	do	Asa Shuck	do	do	do	1.71	120
54	11	Rinehart	Dan H. Rinehart	do	Jan. 23, 1894	do	.18	12
56	12	Hyattville	S. W. Hyatt	do	July 2, 1894	do	1	70
56	12	do	D. W. Hunsinger	do	do	do	.86	60
59	16	South Side	Lee Nansell	Bonanza, Wyo.	July 5, 1895	do	.43	29.3
59	16	Weintz	John Weintz	Hyattville, Wyo.	do	do	1	70
59	16	do	H. W. Meyers	do	do	do	.51	36
59	16	do	Nora O. Meyers	do	do	do	.50	35

CHERRY CREEK, TRIBUTARY OF BOXELDER CREEK.

61	1	Helms No. 3	Henry Helms	Redbank, Wyo.	July 11, 1895	Irrigation	.26	18

LOWER OR BIG CANYON CREEK, TRIBUTARY OF TENSLEEP CREEK.

3	1	Hunsinger No. 1	Jacob Hunsinger	Tensleep, Wyo.	Oct. 15, 1894	Irrigation	2.28	160
15	2	Hunsinger No. 2	do	do	Oct. 1, 1886	do	2.64	185
51	3	Canyon Creek Ditch.	Frank M. Simmons (C. E. Shaw, agent.)	do	Sept. 4, 1893	do	3.64	255

BUFFALO FLAT CREEK, TRIBUTARY OF ALKALI CREEK.

36	1	Buffalo Flat	John J. Smith	Hyattville, Wyo.	1888	Irrigation	.93	65

MEDICINE LODGE CREEK, TRIBUTARY OF PAINT ROCK CREEK.

9	1	George Bayne	D. V. Bayne	Hyattville, Wyo.	May 10, 1885	Irrigation	3.19	223
9	1	do	Estate of George Cassell, F. P. Carr, administrator.	do	do	do	2.53	177
10	2	Wickwire	Byron Wickwire	do	1885	do	.36	25
20	3	Allen & Nelson	Theodore F. Nelson.	do	Apr. 10, 1887	do	1.10	77
20	3	do	Jas. D. Allen	do	do	do	.87	61
26	4	Highland	Lorenzo D. Walu	do	Nov., 1887	do	.49	34
26	4	Walu No. 2	do	do	do	do	.57	40
32	5	Hyatt No. 2	Saml. W. Hyatt	do	May 10, 1888	do	1.21	85
34	6	Anthony	Byron Wickwire	do	Sept. 20, 1888	do	.08	5
34	6	do	David Matthews	do	do	do	3.50	245

COON HOLLER OR COON CREEK, TRIBUTARY OF SPRING CREEK.

39	1	Dutch	John J. Smith	Hyattville, Wyo.	May 17, 1889	Irrigation	.26	18

BEGINNING OF CONSTRUCTION OF DAM AT NORTH END OF DOME LAKE RESERVOIR.

It is further ordered that certificates of appropriation be issued to the said appropriators in accordance with the provisions of the foregoing findings and order.

In witness whereof, the president of the State board of control has hereunto set his hand this 10th day of March, A. D. 1898.

RESERVOIRS.

By drawing on the larger streams when the smaller ones were exhausted it has been possible to utilize a large percentage of the flow from the east side of the range without resorting to storage, but the time is approaching when storage will be necessary if the reclaimed area is to be extended. Storage has been somewhat delayed, because there is no law at present defining and protecting rights to stored water. This is one of the legislative questions to be dealt with in the near future. Much can be done whenever it becomes necessary. The sites for mountain reservoirs are both numerous and valuable. From the summit of Cloud Peak over 100 mountain lakes can be counted, and a large percentage of these will in time be utilized.

Actual construction has begun on only one of these reservoir sites—Dome Lake. The location of this lake is shown in fig. 5, and a detailed sketch of the lake and surroundings is given in fig. 7. The elevation of the lake is 8,720 feet, as determined by the topographers of the United States Geological Survey during the season of 1897. The area of the water surface is 320 acres, the average depth 20 feet, and the total flow of water 6,400 acre-feet. The estimated cost of the reservoir is $50,000. The improvements have been made with the double object of storing water for irrigation and of making this point an attractive summer resort.

The importance of the lakes on the head waters of Piney Creek is clearly shown in the able report of Capt. Hiram M. Chittenden, giving the results of his preliminary examinations of reservoir sites in Wyoming and Colorado.[1] The relative location of these lakes is shown on the Cloud Peak topographic atlas sheet of the United States Geological Survey, the area being mapped during the field season of 1898. From a report by Mr. François E. Matthes, the following facts concerning South Piney Creek have been obtained:

The South Fork of South Piney Creek flows from the snow banks and glaciers east of Cloud Peak, and has therefore an abundant water supply throughout the year. Its valley, above the point where the ditch to Rock Creek begins, is the bed of an ancient glacier, and is thickly covered with morainal deposits of irregular disposition, giving rise to a remarkable number of lakes of all sizes. Among these are Cloud Peak Lake and Mead Lake, shown in fig. 8, both of which

[1] Preliminary examination of reservoir sites in Wyoming and Colorado, by Capt. Hiram M. Chittenden, with monograph on Reservoirs and their effects on the floods of the Mississippi system, by James A. Seddon: House Doc. No. 141, Fifty-fifth Congress, second session. Washington, 1898. 110 pp., 10 folding maps.

have at various times been proposed for reservoir sites. Both are deep and are surrounded by steep mountain sides; the altitude of Cloud Peak Lake is 9,703 feet and of Mead Lake 9,950 feet, approximately. (See Pl. III, *B*.) Unfortunately but one of the two main canyons on the east side of Cloud Peak drains into these lakes. The other (lesser) canyon joins the main canyon half a mile below Cloud Peak Lake.

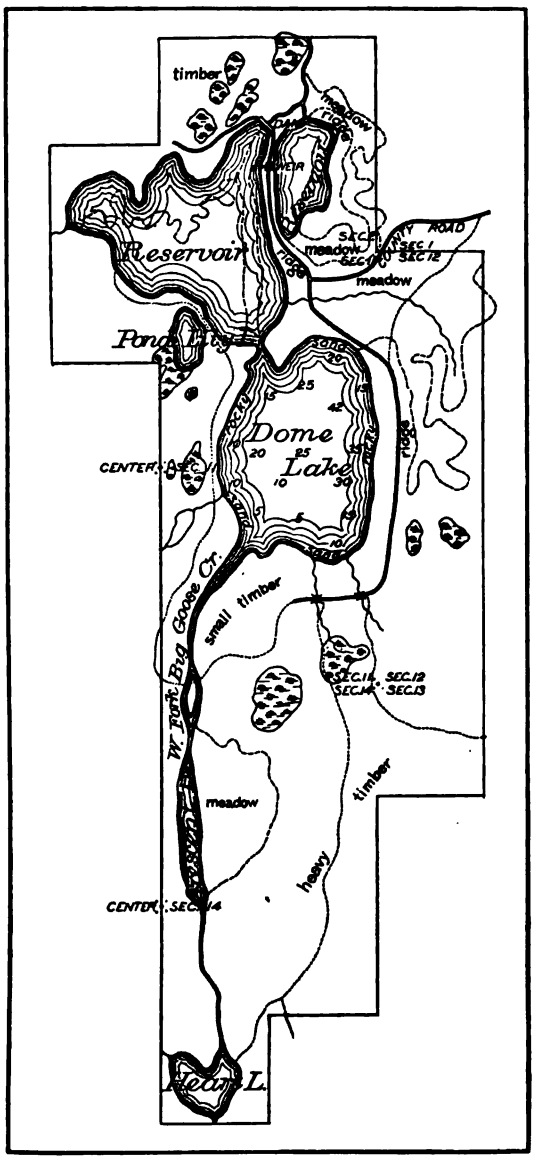


FIG. 7.—Dome Lake reservoir.

Another large body of water, Elk Lake, draining into the South Fork of South Piney Creek, lies on a broad shelf and is very shallow. The lake is at an elevation of 9,850 feet. Its catchment area is very small, almost entirely above timber line, and contains nothing larger than insignificant rills. In spring it probably receives a large amount of water from the melting snowdrifts on the peaks. The outlet of the lake is wide and flat and of a swampy character. The stream at that point is quite small, but increases farther on. It apparently sinks into the ground on leaving the lake, a phenomenon quite common in a country covered with glacial débris. By building a low dam the area of the lake will be considerably increased, but the water supply will be limited practically to that obtained in spring from snow banks which entirely disappear each summer.

The North Fork of South Piney Creek flows through a valley similar

to that of the South Fork. The number of lakes, as shown in fig. 8, is even larger than on that branch, but few are available for water-storage purposes. Among these are the Kearney Lakes, altitude 9,156 feet, in reality one lake, which, however, is fast being converted

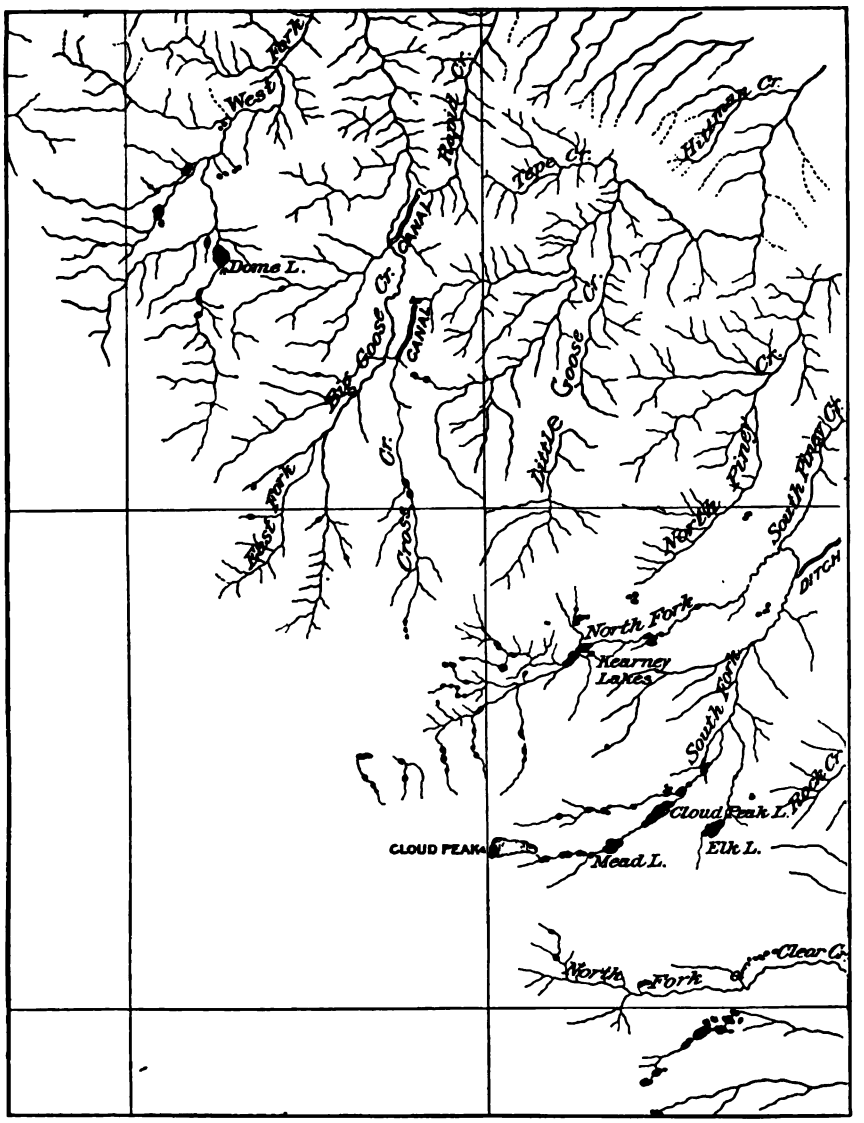


FIG. 8.—Lakes at head of Piney and Goose creeks.

into two separate lakes, as shown on Pl. VII, by the sediment of two small brooks entering near the middle, opposite each other. The twin lakes thus formed are deep and can easily be dammed at the outlet. They receive all the water from the glaciers in the canyons north

of Cloud Peak and that from the perpetual snow banks on the peaks of the main range. It is expected that surveys for a reservoir dam at these lakes will be commenced early next season.

The northern forks only of Clear Creek were mapped during 1898, but a general survey of the entire drainage area revealed the fact that each of the half dozen canyons which form its head waters contains a number of lakes, some of them almost as large as the Kearney Lakes. The entire basin is thickly covered with morainal ridges; it is extremely rough and practically inaccessible.

Sites along Tongue River will serve to increase greatly the acreage that stream will reclaim, while on the western slope the improvement of the lakes on Medicine Lodge and Tensleep creeks will serve not only to double the reclaimed area but to call attention to a region of unsurpassed scenic attractions.

The maps filed in the State engineer's office serve to show the location of the projects on which work was begun and the nature of the improvements proposed.

Names, superficial area, and contents of the reservoirs in the Bighorn Mountains for which permits have been issued by the State engineer.

Name.	Superficial area in acres.	Contents in acre-feet.
Dana reservoir	4	25
Kearney reservoir	146.2	3,801
Dome Lake reservoir	211.2	3,168
Willow reservoir	57.8	650
Barr reservoir	48	450
Treichler & Parsons reservoir	5.1	61.2
Ella reservoir	45	1,000
Denio reservoir	193.75	1,743.75
Cross & Cruse Co. reservoir	21	.....
Elk Lake reservoir	197.55	2,570
Cloud Peak reservoir	170	2,500
South Piney reservoir	95.4	1,050

ADMINISTRATIVE QUESTIONS.

The commissioners in charge of the districts described in this bulletin have to deal with unusual conditions. The division of a stream among users is a difficult problem under the most favorable circumstances, but the commissioners of these districts are confronted with complications seldom encountered in equal measure elsewhere. These are:

1. The interchange of water between streams in the same district and its transfer across district boundaries.

OUTLET OF KEARNEY LAKE RESERVOIR ON NORTH PINEY CREEK.

2. The frequent use of streams as part of a ditch or canal and making not one stream but three or four streams part of a single system.

3. The attaching to one piece of land of rights from more than one stream through one or more ditches.

4. The construction of canals to carry water across divides in remote and inaccessible locations in the mountains, thereby rendering the regulation of head gates expensive and difficult and the measurement of stream flow practically impossible.

Even when the streams are gaged and the commissioner knows the supply to be divided he is often unable to perform his work to his own satisfaction or that of irrigators. The wide and rapid fluctuation of streams is to blame for this. From the records of the gagings of Clear Creek, made by the State engineer and the Geological Survey, it is seen that the discharge ranges from three or four times the total volume appropriated to about one-third this volume, and that at times these two extremes are reached within a few days of each other.

The gaging station is below the mountain ditches, and its record does not show what they divert, but it does show how rapid must be the commissioner's movements to protect the rights to the 232 second-feet appropriated. On May 23, 1896, as shown in fig. 3, less than 100 second-feet was passing over the weir; on the 24th there was over 200. On June 3 a flow of 504 second-feet permitted all users to waste water, if they so desired. Three days later the discharge was less than the amount appropriated. On the 19th the flow was 209 second-feet; on the 29th it was 82. The distance from the highest to the lowest head gate on this stream is 50 miles, and an examination of the map (fig. 2) will show the haphazard location of the appropriations and the rapid changes necessary to protect these rights when the demand begins to exceed the supply. The commissioner would have enough to do in times of scarcity to regulate this stream only, but he has in addition to watch the fluctuations of half a dozen others and keep track both of their natural discharge and of the water turned in from other streams.

While doing this he can only estimate the volume to be distributed. From the highest ditch on Clear Creek to the foot of the mountain is a day's journey. It takes half that time to go from the highest land irrigated on Rock Creek to the head gate of the Piney feeder in the mountains along that stream. From the last ditch on Prairie Dog to the first on the stream which supplies it the distance is 40 miles in one direction, and it is an equal distance to the last ditch along the valley of that stream in almost the opposite direction. Without telephone or telegraph connection, the commissioner can deal only with what he sees. Under the circumstances the success achieved has been little less than marvelous.

The water turned from Big Goose Creek into Little Goose Creek enters that stream 9 miles from and 2,000 feet above the land first

irrigated. The head of the ditches can only be reached after a day's journey, and frequent inspections can not be made. Because irrigators can not know the facts, they are all the more likely to resent any interference with their supply. Appropriators of the natural flow are sometimes disposed to believe that those dependent on some other source get more than their share, and vice versa. Users of water along Piney Creek, Big Goose Creek, and other large streams do not look with favor on the diversions into other drainage basins where the subsequent regulation is so expensive and difficult. It is, therefore, a high tribute to the honesty and tact of the commissioners and superintendent to say that they have thus far performed their duties in such a way as almost entirely to avert litigation. To enable them to continue this, however, their labors should be supplemented by comprehensive measurements of the discharge of these several streams. The turning of water across divides and the use of a stream as part of a ditch is no doubt economical, but unless the methods so largely employed here are supplemented by numerous stream gagings, it is hard to see how commissioners are to distribute successfully a supply coming from three or four sources.

Lack of gagings add to the perplexities of the State engineer. It is a part of his duty to refuse permits for additional ditches when the water supply is exhausted. So long as he has no knowledge of the volume being diverted, nor where it goes, he has to depend largely on conjecture. The extensive construction of reservoirs along the channels of these streams which is certain to result in the near future, and the use of their channels to transport the stored water to the place of use, will aggravate these complications. That they can all be removed is not to be doubted, but to accomplish this it will be necessary to have a full understanding of all the conditions, and foremost among these is the amount of water there is to be stored, divided, and used.

INDEX.

	Page.
Administrative difficulties, discussion of	58–60
Amsden Creek, appropriations from	46–48
Barr reservoir site, description of	58
Big Canyon Creek, appropriations from	54
Big Goose Creek, appropriations from	43–45
map showing lakes at head of	57
Bighorn Mountains, plate showing view of	11
Billy Creek ditch, irrigation from	19, 20, 23
Blue Gap ditch, irrigation from	20, 23, 27
Board of control, work of	14–16
Bond, Fred, stream measurements by	30
Boxelder Creek, appropriations from	52
Broken Back Creek, appropriations from	53
Buffalo, stream measurements near	30–31
Buffalo Flat Creek, appropriations from	54
Burton ditch, irrigation from	20, 23
Canton ditch, irrigation from	20, 23
Chittenden, H. M., cited	55
Clear Creek, measurements of	28–30
map showing irrigation systems on	29
diagram showing discharge of	31
appropriations from	31–32, 38
diversion of water from	33–35
Cloud Peak, plate showing view of	11
Cloud Peak Lake reservoir site, description of	55–56, 58
Cook ditch, irrigation from	20, 23, 27
Coon Creek, appropriations from	54
Crazy Woman Creek, appropriations from	18–28
Crooked Creek, appropriations from	52
Cross & Cruse Co. reservoir site, description of	58
Dana reservoir site, description of	58
Denio reservoir site, description of	58
Devoe ditches, irrigation from	20, 23, 27
Dick ditch, irrigation from	20, 23, 27
Dome Lake reservoir, plate showing	54
description of	55, 58
map showing	56
Dundee ditch, irrigation from	37
Duty of water, amount of	24–25, 38
Elk Lake reservoir site, plate showing	34
description of	56, 58
Ella reservoir site, description of	58
Fisher ditches, irrigation from	37
Fort Collins ditch, irrigation from	20, 23, 27
French Creek, appropriations from	33–35, 37
Gorgen ditch, irrigation from	37
Harris ditches, irrigation from	20, 23, 27
Hewes Creek, appropriations from	46, 48
Holt ditch, irrigation from	20, 23, 27
Johnson Creek, appropriations from	38
Kearney Lake reservoir site, description of	57, 58
plate showing view of	58
Kelly Creek ditches, irrigation from	20, 23
Kennedy ditch, irrigation from	20, 23, 27
Kingsbury ditches, irrigation from	20, 23
Land reclaimed, acreage of	12–13
Last Chance ditch, appropriations from	43–45
Little Canyon Creek, appropriations from	54
Little Goose Creek, appropriations from	43–45
map showing lakes at head of	57
Little Tongue River, map showing ditches from	46
appropriations from	49–50
Loss of water in transmission, allowance for	38–40
Lower Canyon Creek, appropriations from	54
Massacre Hill, plate showing view of	36
Matthes, F. E., cited	55
Mayhew & Gorgen ditch, irrigation from	37
Mead Lake reservoir site, plate showing	34
description of	55–56
Medicine Lodge Creek, appropriations from	54
Miller ditch, irrigation from	20, 23, 27
Mitchell & Long ditch, irrigation from	20, 23, 27
Moeller ditches, irrigation from	37
Moreton ditches, irrigation from	20, 23, 27
Muddy Creek ditch, irrigation from	20, 23
Newell, F. H., letter of transmittal by	9
No Wood River, appropriations from	50–52
North Fork ditches, irrigation from	19, 20, 23, 27
North Fork of Crazy Woman ditch, irrigation from	20, 23, 27
Otter Creek, appropriations from	53
Paint Rock Creek, appropriations from	53–54
Piney Creek, plate showing view of	32
plate showing reservoir sites on	34
diversion of water from	35–36
map of ditches diverting water from	35
appropriations from	38
map showing lakes at head of	57
Prairie Dog Creek, appropriations from	35–36
map of ditches diverting water to	35
Px ditch, irrigation from	20, 23
Red Bark ditch, irrigation from	20, 23

DEPARTMENT OF THE INTERIOR

WATER-SUPPLY

AND

IRRIGATION PAPERS

OF THE

UNITED STATES GEOLOGICAL SURVEY

No. 24

WASHINGTON
GOVERNMENT PRINTING OFFICE
1899

UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

WATER RESOURCES

OF THE

STATE OF NEW YORK

PART I

BY

GEORGE W. RAFTER

WASHINGTON
GOVERNMENT PRINTING OFFICE
1899

CONTENTS.

	Page.
Letter of transmittal	7
Introduction	9
General statements	10
Favorable natural conditions	11
Artificial modifications	11
Water storage	12
Erie Canal	13
Value of water to industries	14
Ownership of water	14
Physical conditions	16
Mountains and forests	16
Temperature and precipitation	18
Rocks and stream flow	21
River systems	23
St. Lawrence system	24
Niagara River	24
Genesee River	25
Oswego River	27
Black River	29
Streams flowing into St. Lawrence River	30
Lake Champlain system	31
Hudson River system	33
Mohawk River	35
Schoharie Creek	35
East Canada Creek	36
West Canada Creek	38
Other tributaries of Mohawk River	40
Hoosic River	40
Battenkill River	40
Fish Creek	41
Sacundaga River	42
Schroon River	43
Tributaries south of Mohawk River	43
Allegheny River system	44
Susquehanna River system	44
Delaware River system	46
Streams of Long Island	47
Available water supply	48
Run-off of Niagara River	48
Run-off of St. Lawrence River	65
Run-off of inland streams of New York	66
Discharge measurements of Eaton and Madison brooks	67
Discharge measurements of Oatka Creek	69
Discharge measurements of Genesee River	70
Discharge measurements of Hemlock Lake	75
Discharge measurements of Skaneateles Lake	77

Available water supply—Continued. Page.
Run-off of inland streams of New York—Continued.
Discharge measurements of Hudson River 79
Discharge measurements of Croton River 82
Maximum and minimum flow of streams in New York 87
Floods in Chemung River 87
Low-water flow of Oatka Creek 90
Low-water flow of Genesee River 90
Low-water flow of Hemlock Lake 92
Low-water flow of Morris Run 93
Low-water flow of West Branch of Canadaway Creek 94
Low-water flow of Skaneateles Lake 96
Low-water flow of Oswego River 96
Low-water flow of Black River 96
Low-water flow of Mohawk River 97
Low-water flow of Hudson River 97
Low-water flow of Croton River 98
Summary of knowledge of low-water flow 98
Index 100

ILLUSTRATIONS.

Page.
PLATE I. Erie Canal at the city of Buffalo 12
II. *A*, Beaver Meadow, near Indian Lake, a typical reservoir site in the Adirondacks; *B*, Bog River in the Adirondacks 16
III. Drainage area of Genesee River 24
IV. *A*, Upper and Middle Falls of Genesee River, at Portage; *B*, Genesee River Canyon below Middle Falls, at Portage 26
V. Middle and Lower Falls of Genesee River at Rochester 28
VI. *A*, Dam at the High Falls of East Canada Creek; *B*, High Falls at Trenton on West Canada Creek 38
VII. Big Falls of Battenkill River 40
VIII. *A*, Hudson River above Luzerne; *B*, Sacundaga River near Luzerne 42
IX. Drainage area of Schroon River 44
X. Canyon of Genesee River between Mount Morris and Portage 70
XI. *A*, Erie Canal aqueduct and south side of Main street bridge, Rochester; *B*, Great flood of 1865 at Rochester, showing lumber lodged against aqueduct bridge 90
XII. Upper Falls of Genesee River at Portage 92
XIII. High Falls of Mohawk River at time of low water 96
FIG. 1. Index map of rivers of New York 23
2. Discharge of Genesee River at Mount Morris, New York, 1893 to 1896 73
3. Flood flow of Genesee River, May 18–24, 1894 74
4. Discharge of Hudson River at Mechanicville, New York, 1888 to 1897 81

LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF HYDROGRAPHY,
Washington, November 26, 1898.

SIR: I have the honor to transmit herewith a manuscript entitled Water Resources of the State of New York, prepared by Mr. George W. Rafter, and to recommend that it be published in the series of pamphlets upon Water Supply and Irrigation. The data herewith presented were brought together by Mr. Rafter during 1897 and transmitted early in February, 1898. Publication has been somewhat delayed by various obstacles which could not be readily overcome. The data are, however, of general interest and value, not only to the people of New York State, but also to engineers and persons in all parts of the country interested in the development and utilization of the water resources. Particular attention is given to the discussion of floods and low-water flow, these being to a large extent the determining factors in considerations of the utilization of water power.

Very respectfully,

F. H. NEWELL,
Hydrographer in Charge.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

WATER RESOURCES OF THE STATE OF NEW YORK, PART I.

By GEORGE W. RAFTER.

INTRODUCTION.

The preeminent position of the State of New York is due almost entirely to her great natural water resources. Reaching from the ocean on the east to the Great Lakes on the west, she has gathered to herself the treasures of the foreign world as well as those of half the Western Continent. Her inland rivers, with their great water powers, have been in the past and will continue to be in the future a perpetual source of wealth. Taking into account the commercial supremacy guaranteed by the Erie Canal, it may be said that the history of the State's progress during the nineteenth century is largely a history of the development of her water resources. It is the purpose of the author in this report to relate briefly not only in what manner these resources have been employed, but to indicate the recent lines of development and the probable future of the State if her water is utilized to the fullest degree. It is proposed to describe in a general way the river systems, giving brief descriptions of several of the more important utilizations of water in New York, together with a discussion of some of the economic problems confronting the people of the State.

As regards the water power of New York, it may be noted that the Tenth Census of the United States, 1880, Vols. XVI and XVII, gives in great detail the statistics of the main water powers as they existed in 1882. Many of these show considerable increase at the present time, although the new works are for the most part similar to those described in the census report, and hence present few additional features of interest. Several of the recent plants, however, are on quite different lines both as to their scope and as to the method of development adopted. It has therefore seemed more important to describe a few of the new plants and to give the main facts of the great storage projects of the Hudson and Genesee rivers than to spend time on small and relatively unimportant powers.

The peculiar relation of the State to water-power development on the main rivers of New York should be here mentioned. Owing to the circumstances of the early settlements and the development ot the canal system, the State has assumed ownership of the inland waters, or, at any rate, of all streams used as feeders of the canals. This assumption has worked injustice to riparian owners, and is at present a bar in the way of the full development of important streams by private enterprise.

The data embodied in this report have been gathered from many sources—the annual reports of the State engineer and surveyor, the superintendent of public works, the forest commission, the State board of health, the State weather service, and other public documents. The data in the reports on the Water Power of the United States, Tenth Census, have been used in many cases where later data are not available. During the years 1896 and 1897 the author, in addition to his regular duties in the State engineer's department, gathered a large amount of information bearing on the water resources of the State and not published in the annual reports of the State engineer's department. Much of this is in the way of piecing out earlier information and bringing the subject up to date. By the courtesy of the State engineer and surveyor these special data have been embodied in the present report.

The figures as to drainage area have been obtained by checking on French's map, published in 1860, those given in the reports on the water power of the United States, Tenth Census, so far as they are available, and by planimeter measurement on the topographic atlas sheets of the State made by the United States Geological Survey. Bien's Atlas of the State of New York has also been used as a check in some cases, and a number of areas have been taken from the report of the Deep Waterways Commission.

The elevations of points above tide water have been compiled from all available sources of information, such as Dictionary of Altitudes in the United States, Bulletin No. 76 of the United States Geological Survey; the reports of the New York State survey and railway canal profiles; the topographic atlas sheets of the United States Geological Survey, and the reports on the water power of the United States, Tenth Census, 1880.

GENERAL STATEMENT.

A report of this character is prepared for the benefit of two classes: First, professional or business men who read during leisure hours in order to add to their stock of general information; second, engineering specialists, physicists, and men of expert scientific attainments generally who desire full details as part of their stock of professional knowledge. The latter class will naturally study the details, while

for the former a succinct statement of the results of the study is generally sufficient. It is from this point of view that a statement of the general results of the study of the water resources of New York is here introduced at the beginning of the report.

FAVORABLE NATURAL CONDITIONS.

New York State is great in water resources, not only by virtue of her position between the Atlantic Ocean and the Great Lakes, but because topographic, geologic, and climatic conditions have combined to make her the highway of commerce as well as the manufacturing center of the United States. Some of the contributing causes to this preeminent position may be found in her mountain systems, affording three great water centers, from which large streams descend to the neighboring lowlands, affording large opportunities for the economic development of water power. As regards water power, the other chief contributing causes are the possession, as part of her domain, of Niagara and St. Lawrence rivers, with their extensive possibilities for future water-power development.

A study of the climatology of New York shows that in nearly every portion of the State the amount and distribution of the rainfall are such as to insure a large enough run-off of streams to furnish, even under natural conditions, considerable water power.

ARTIFICIAL MODIFICATIONS.

Natural conditions have been largely interfered with by the cutting off of forests and the consequent extensive development of the agricultural interests of the State. As a tentative proposition, it is assumed that the general cutting off of the forests of New York State has decreased the annual run-off of streams issuing from the deforested areas to a depth of from 4 to 6 inches per annum.

The run-off of Niagara River has been commonly assumed, on the authority of the Lake Survey, at about 265,000 cubic feet per second. The recent studies indicate that the extreme low flow of a cycle of minimum years may be not more than 60 per cent of this figure. From this point of view the people of the State of New York have the greatest possible interest in any project which would tend to decrease the low-water run-off of that stream. Such interest is equally pronounced in the case of St. Lawrence River.

Measurements of discharge of a number of the inland streams of New York indicate considerable variations in water yield in different parts of the State. For instance, Genesee River, in the western part, in 1895 gave, with a rainfall of 31 inches, a minimum flow for the year of 6.67 inches. The drainage area of this stream is mostly deforested, whence it results that serious floods are frequent. For

example, from May 19 to 24, 1894, the total discharge was nearly 6,900,000,000 cubic feet, the maximum, which occurred at 3.30 a. m., May 21, being 42,000 cubic feet per second. The drainage area above the point where this flood occurred is 1,070 square miles.

The lowest annual run-off thus far measured in the State of New York is that of the Hemlock Lake drainage area, where, in 1880, the total run-off from an area of 43 square miles was only about 3.35 inches.

Oswego, Mohawk, and Hudson rivers and their tributaries in this State all have large pondage on natural lakes, which, with other conditions, tend to maintain the low-water flow. Croton River presents surface geological conditions which tend to increase its low-water flow. Without going into detail, we may say that these streams will yield a minimum flow of about 0.3 of a cubic foot per square mile per second. Variations from this limit are given in the chapters specially discussing minimum flow.

As a typical flood stream of the State, Chemung River may be mentioned, where serious floods, due to deforestation of a mountainous drainage area, have become so common as to necessitate the carrying out of extensive protection works at the large towns on that stream.

WATER STORAGE.

Large development of water power on Genesee River has led to a demand for extensive storage reservoirs on that stream. The surveys made by the State indicate that a storage reservoir of 15,000,000,000 cubic feet capacity can be constructed at a cost of $2,600,000, or at the rate of about $173 per million cubic feet stored. It is considered that the construction of such a reservoir is commercially feasible, and, provided the State legislature will grant the necessary permission, the project will probably be carried out by a private company. The developed water power of Genesee River has increased from about 6,000 horsepower in 1882 to about 18,000 horsepower in 1898.

Extended studies have also been made of the possibilities of water storage on Hudson River, where the water power has increased from less than 13,000 horsepower in 1882 to something like 55,000 horsepower at the beginning of 1898. The studies, so far as carried, show that it is possible to create on that stream a continuous, permanent power of about 175,000 horsepower. Probably when the studies are complete it will appear that considerably more than this can be developed at a cost which will be commercially feasible.

The great power developments on Niagara River at Niagara Falls, and on St. Lawrence River at Massena, are the most significant industrial movements now taking place in the United States. The future power of these two streams may easily be placed at several hundred thousand horsepower.

ERIE CANAL AT THE CITY OF BUFFALO.

ERIE CANAL.

Erie Canal, a view of which is given on Pl. I, was the first great development of the internal water resources of New York, and grew out of the demand for transportation facilities between the Atlantic seaboard and the Great Lakes. The impulse which it gave to the development of New York State, and of the entire territory tributary to the Great Lakes, can hardly be estimated. Taking into account its far-reaching consequences, it may be considered the greatest public work thus far carried out in the United States. Nevertheless, Erie Canal has not only passed its day of usefulness, but, to some extent, stands in the way of future development, the chief cause for this being a too pronounced regard for the canal's former greatness. The historical matter cited in the body of the report may serve to indicate how strongly the feeling that Erie Canal should be maintained in perpetuity has been impressed upon the people of the State of New York.

By way of illustrating the rise and decline of Erie Canal, it may be cited that in 1837 the total freight carried was 1,171,296 tons, valued at $55,809,288; in 1880 the total freight carried was 6,457,656 tons, valued at $247,844,790; in 1895 the total freight carried was 3,500,314 tons, valued at $97,453,021. Statistics show that the great bulk of all the freight now carried on Erie Canal is through freight carried for Western producers, local business being only a small per cent of the whole. Statistics show that freights are now carried by railways as cheaply as they can be carried by the canal, and this, too, at a profit, while the canal, in order to obtain any freight at all, has been obliged to do away with all tolls, thus making the cost of shipment by canal the bare cost of transportation proper.

In 1895 an improvement of Erie Canal was authorized at a cost of $9,000,000. The work of this improvement is now in progress. Recently it has been found that the cost will be $16,000,000, instead of $9,000,000, as originally expected. On this basis, and throwing out of the account former expenditures, we may say that Erie Canal will cost the people of the State of New York annually at least $1,230,000. Assuming a traffic for the enlargement of the canal of 5,000,000 tons per annum, carried 200 miles, we have a total of 1,000,000,000 ton-miles per annum on which the people of the State of New York must pay in the way of interest and cost of maintenance and operation about 1.25 mills per ton-mile, while canal freights now average about 1.2 mills per ton-mile; hence the people of the State of New York will be obliged to pay under the new conditions over 50 per cent of the total cost of the transportation. At present the local canal freights are only 15 per cent of the total.

Owing to her extensive inland-navigation system the experience of New York as to loss of water from artificial channels has been very

extensive. Measurements made at different times show that in a canal of the dimensions of the original Erie Canal, which had a section of 40 feet water surface, 28 feet bottom, and 4 feet depth, there should be provided, in order to cover the evaporation and percolation losses, a water supply of about 100 cubic feet per mile per minute. Details relating to this special subject may be found further on.

The State early adopted the policy of leasing surplus waters of Erie Canal for power purposes. The most extensive development growing out of such leases is that at Lockport, where several thousand horsepower are in use supplying establishments valued at about $2,500,000 a year, and employing nearly 1,900 operatives, with an annual product of about $3,000,000.

VALUE OF WATER TO INDUSTRIES.

Water power is extensively sold at Oswego, Cohoes, and Niagara Falls, and to some extent at Rochester. It will also be extensively sold at Massena when the development there is completed.

The value of the internal waters of the State to some of the leading industries, such as the lumber industry and the wood-pulp and paper industry, may be noted. On Hudson River from 1851 to 1897, inclusive, the total number of logs taken to market by water transportation was 23,313,585, these market logs furnishing 4,662,717,000 feet B. M. of lumber. The cost of driving logs from the head waters of the Hudson to the Big Boom above Glens Falls is said to be from 50 to 75 cents per thousand feet B. M.

The wood-pulp and paper industry is developed in New York State to a point beyond that reached in any other State of the Union. On January 1, 1898, there were at least 125,000 net water horsepower in use in the State in the production of mechanical wood pulp, while probably from 30,000 to 35,000 more are consumed in operating paper mills.

One obstacle to the easy operation of water power in this State is the formation on many streams of frazil or anchor ice. A study of the formation of frazil and anchor ice, as made by the Montreal harbor commissioners, indicates that it may be possible to learn in the future how to remedy this difficulty.

OWNERSHIP OF WATER.

The sand areas of Long Island present conditions of water yield different from those of the other drainage areas of the State. We have here an extended region of coarse, deep sand, into which the rainfall sinks easily, there being almost no surface run-off. These sand areas form subterranean reservoirs, from which from 0.7 to 0.8 cubic foot per square mile per second may be drawn, the same as from artificial reservoirs on the earth's surface, these natural underground

reservoirs possessing the advantage of furnishing a filtered water of a high degree of purity.

The taking of the water supply of Brooklyn from the sand areas of Long Island has led to the development of legal principles relating to rights in underground water somewhat different from those derived from the common law of England. The decision in a test case now before the courts is, in effect, that when subterranean water is taken in large quantity for the supply of cities or for manufacturing purposes the party taking it is liable to the adjacent landowners the same as in the case of diverting surface water.

Owing to the development of the internal navigation system, and the consequent assumption on the part of the courts and State officials that the State's rights to the inland waters were, in effect, paramount to all other rights, no general mill act has ever been enacted in the State. Nevertheless, the demand for water storage on the streams of the northern part of the State and on St. Lawrence River, which are not in any way tributary to Erie Canal, has led to the enactment of a number of special laws which have the force of mill acts in that they grant the right of eminent domain for the purpose of improving the hydraulic power of streams. This phase of development of the laws of this State relating to riparian rights is an exceedingly interesting one.

Titles to lands under water and water rights have been considerably complicated in New York because of the peculiar circumstances of the early settlement. It is well-established law that Hudson and Mohawk rivers belong to the State, while the Genesee and the other large rivers belong to the riparian owners. A confusion of ideas arising out of such contradictory facts as these has undoubtedly assisted in obscuring the real relations of the State to riparian owners in New York.

In the case of Black River large quantities of water have been diverted for the supply of Black River and Erie Canal, which has been compensated for in kind by the construction of a system of State reservoirs on the head waters of that stream capable of storing nearly 3,800,000,000 cubic feet. The State has further recognized the rights of riparian owners in the Black River reservoirs by creating a commission of owners and users of water power on Black River to manage the discharge from the reservoirs.

Skaneateles Lake presents a case where the State, having originally appropriated water for the supply of Erie Canal, has later, by act of legislature, allowed the taking of the said water for a municipal supply.

With restrictive legislation repealed and a proper mill act enacted, we may hope ultimately to develop in New York approximately 1,518,000 gross horsepower, worth to the people of the State anywhere from $150,000,000 to $200,000,000 a year, or as much as the present entire agricultural product of the State.

PHYSICAL CONDITIONS.

Considering only the broader topographic features, the streams of the State may be pictured as coming from three main water centers. The first of these in importance is the Adirondack area, the peaks of which are over 5,000 feet in height. Next to this are the Catskill Mountains, in the southeastern part of the State, the greatest heights of which are about 4,000 feet; and third are the highlands of the southwestern portion of the State, portions of the Allegheny Plateau. In extent the Adirondack Region is much the largest, and owing to this fact and its higher elevation it is the most important water center of the State. The Catskill Region, from its lower altitude and from changes introduced by cutting off the forests, is much less valuable in yield of water. The issuing streams are flashy and uncertain, pouring down destructive floods in spring and running nearly dry during the summer and fall. It is, without doubt, largely owing to this fact that water-power development has made less progress in this part of the State than in the other power-producing sections. The Allegheny Plateau has also greatly deteriorated in water-yielding capacity on account of deforestation. The serious effect of such decrease is discussed later in connection with the Genesee River storage project.

MOUNTAINS AND FORESTS.

The mountain belt included in the Adirondacks proper—the Bouquet, Schroon, Kayaderosseras, and Luzerne ranges, with the Highlands immediately to the west—has come to be commonly known as the Adirondack Plateau. Describing this broadly, it may be considered as bounded on the east by Lake Champlain, on the west by the valley of Black River, on the north by the farming regions of the St. Lawrence, and on the south by those of the Mohawk Valley. The mountain belt proper, however, occupies only the eastern and southern part of the Adirondack Plateau. Its greatest width is about 40 miles. The mountain ranges, however, are not always distinct; sometimes these are lateral spurs interlocked and sometimes single mountains occupy the space between the ranges, filling the valleys.

From the Adirondack Plateau streams flow to the north, southeast, and west. The principal streams flowing north, east, and west to the St. Lawrence system are Moose, Beaver, Oswegatchie, Grass, Raquette, St. Regis, Salmon, Saranac, Ausable, and Bouquet rivers. The southern streams, which all belong to the Hudson system, are Sacundaga, Indian, Cedar, Opalescent, Boreas, and Schroon rivers, and East Canada and West Canada creeks. All these streams head in lakes, of which the most important, tributary to the St. Lawrence, are Placid, Saranac, St. Regis, Loon, Rainbow, Osgood, Meacham, Massawepie, Cranberry, Tupper, Smiths, Albany, Red Horse Chain, Beaver, Brandeth, Bog

A BEAVER MEADOW, NEAR INDIAN LAKE, A TYPICAL RESERVOIR SITE IN THE ADIRONDACKS.

B. BOG RIVER IN THE ADIRONDACKS.

River Chain, Big Moose, Fulton Chain, Woodhull, Bisby, Raquette, and Blue Mountain. Typical views are given on Pl. II.

Following are the principal lakes of the Adirondack Plateau tributary to the Hudson system: Pleasant, Piseco, Oxbow, Sacundaga, Elm, Morehouse, Honnedaga, West Canada, Wilmurt, Salmon, Spruce, Cedar, Lewey, Indian, Rock, Chain, Catlin, Rich, Harris, Newcomb, Thirteenth, Henderson, Sanford, Colden, Boréas, Elk, Paradox, Brant, Schroon, and Luzerne.

The great forest of northern New York occupies the central part of the Adirondack Plateau, and deserves notice from its importance as a conservator of the streams issuing from that region. According to a map accompanying the report of the forest commissioners of New York for 1891, the outlines of the great forest are substantially as follows: Its eastern boundary coincides quite closely with a line drawn through Keene Valley and thence along the valleys of Schroon River and the upper Hudson; its southern boundary is for the main part identical with that of Hamilton County and the town of Wilmurt, in Herkimer County, although in some places the forest extends a short distance into Fulton County; its western boundary is the county line between Lewis and Herkimer counties; its northern boundary runs in an irregular line from a point near Harrisville, on the Lewis and St. Lawrence County line, to the Upper Chateaugay Lake, which is situated near the line between Franklin and Clinton counties. This territory contains about 3,590,000 acres, of which 3,280,000 acres are considered to be covered with dense forests. Within this region there are from 1,300 to 1,400 lakes and ponds, while from it the eighteen important streams just enumerated diverge in every direction. The general elevation of the Adirondack Plateau is about 2,000 feet above the level of the sea. Little discussion is needed, therefore, to show the great value of this elevated forest-covered plateau as a conservator of the natural waters of the State.

One important utilization of the waters of this State formerly was the carrying of logs to market through the various streams. By reason of the clearing off of the forests, that business has gradually declined, until, except in the Adirondack Plateau, it is now of little importance. It has been the policy of the State for a number of years to acquire, as far as possible, by tax title and purchase, bodies of land in the Adirondack forest for the purpose not only of conserving the forests in order to increase the yield of streams, but for the further purpose of creating a forest park worthy of the great Commonwealth of New York. In order to carry out this project the forest-preserve board has been empowered to purchase lands within the forest, or, failing to agree on terms with the landowners, to take lands under condemnation proceeding.[1]

[1] The State holdings in the Adirondack Region up to the year 1895 may be determined by reference to a map of the Adirondack forest and adjoining territory as issued by the fisheries, game, and forest commission in 1895.

The Adirondack Plateau is a rugged, rocky region, sparsely populated, and worthless for agriculture. Its chief value lies in a complete utilization of such natural resources as attach to its unparalleled water-yielding capacity. From this point of view it may easily become an important factor in the future development of New York. To insure this result the water yield of every stream of the region needs to be conserved by reservoir systems.

TEMPERATURE AND PRECIPITATION.

In 1826 an elaborate system of meteorological observations at the State academies was inaugurated by the board of regents of the University of New York and was continued until 1863. During a portion of this period, and later, a large amount of data was obtained by volunteer observers of the Smithsonian Institution and at military posts. In 1871 the United States Signal Service took charge of work of this character, and in 1889 the State meteorological bureau was organized. There is, therefore, a large accumulation of material regarding the local climate, such that an account of it would extend beyond the limits of this paper. For details reference should be made to the volumes on meteorology published by the board of regents of the State University; also to the bulletins and annual reports of the State meteorological bureau and of the United States Weather Bureau.

To facilitate the study of meteorological data the individual stations have been grouped in accordance with topographic features and geographic position, the subdivisions being as shown in the accompanying table. The names indicate in a general way the relative position, the Western Plateau including the portion of the Appalachian Highlands west of Seneca Lake, and the Eastern Plateau the remainder of the Appalachian Highlands from Seneca Lake eastward to the Hudson Valley.

The average annual temperature is generally taken as decreasing with altitude at the ratio of 1° F. to every 300 feet of elevation, the rate being somewhat below this average in winter and above it in summer. An approximate determination for the State indicates that the rates of decrease are .3° F. per hundred feet elevation for the winter, and .4° F. per hundred feet for the summer. For the mountains of northern New York a much smaller variation than .3° F. appears to hold for the winter months.

Average monthly and annual temperatures for the 22-year period, 1871–1892.(a)

	Western Plateau.	Eastern Plateau.	Northern Plateau.	Atlantic coast.	Hudson Valley.	Champlain Valley.	St. Lawrence Valley.	Great Lakes.	Central lakes.	Mohawk Valley.	Average of the ten regions.
Altitude (feet)	1,287	1,070	1,578	82	221	186	431	484	645	639	662
January	22.0	21.3	16.0	30.5	21.5	16.3	15.9	23.4	24.2	21.0	21.6
February	23.6	22.5	16.8	31.6	26.9	17.5	17.3	24.3	25.8	22.8	22.9
March	28.5	28.6	24.0	35.9	38.2	25.9	26.5	29.9	30.6	28.8	29.2
April	41.7	42.0	36.8	46.7	46.2	40.8	40.4	42.0	44.2	42.8	42.3
May	54.8	55.0	57.8	57.6	58.8	55.2	55.5	54.8	57.3	55.8	55.7
June	64.3	64.8	60.3	67.0	68.1	64.7	64.2	64.9	66.0	65.0	65.0
July	68.6	68.6	63.8	72.3	72.0	69.9	68.2	69.8	70.8	69.2	69.3
August	66.6	66.3	62.5	71.1	69.6	67.5	65.9	68.1	68.7	67.3	67.4
September	59.3	61.5	55.0	65.3	62.8	58.6	58.4	61.1	61.6	60.0	60.4
October	47.3	47.2	43.3	55.1	50.8	46.9	45.7	49.3	49.6	48.0	48.3
November	35.5	35.6	31.0	43.9	39.0	34.5	33.2	37.3	37.1	35.0	36.3
December	26.7	25.9	21.2	34.5	28.5	21.8	22.2	28.4	28.3	25.8	26.3
Average	44.8	44.7	40.3	50.8	48.4	43.2	42.8	46.0	47.0	45.2	45.4

a From fifth annual report of the State weather bureau.

The intimate relation which exists between air circulation and precipitation in New York is one of the most interesting facts to be noted. Owing to lack of moisture in the continental interior, northwest winds in the spring, summer, and fall are essentially dry. In winter their dryness proceeds from low temperature and consequent small vapor-carrying capacity. The winter precipitation is due almost entirely to storm areas passing either actually across or in the vicinity of this State and deriving their supply of vapor from the inflow of moist air which they induce, either from the Atlantic Ocean or from the Gulf Region.

The winter months—December, January, and February—have somewhat less precipitation than either of the other seasons, although in the vicinity of the Atlantic coast, on the southwestern highlands of the State, and in the region of the Great Lakes the winter precipitation is relatively large.

In the spring rising temperature produces a modification and shifting of pressure systems, the winds decreasing in velocity and their directions being more variable than in winter. The frequent showers occurring in April and May appear to be due more than at any other time to the effect of an admixture of air having different temperatures.

In summer the Gulf of Mexico and the Atlantic Ocean contribute large supplies of moisture to northward-moving air currents, and, although cyclonic depressions are less frequent than at any other season, the rainfall accompanying each storm is heavy, and in New York the maximum seasonal precipitation, amounting as an average for the whole State to 10.96 inches, occurs in this season.

As regards the fall months, the rainfall of September is usually light in the region east of the Great Lakes, while in October the maximum general rainfall occurs. As regards meteorological conditions, winter may be considered as beginning in November.

Average precipitation in New York State, in inches.

	Western Plateau.	Eastern Plateau.	Northern Plateau.	Coast region.	Hudson Valley.	Champlain Valley.	St. Lawrence Valley.
Altitude (feet) *a*	1,307	1,056	973	132	230	262	414
January	2.52	2.52	3.11	3.47	2.89	1.73	2.19
February	2.23	2.34	2.78	3.22	2.26	1.35	2.15
March	2.51	2.46	3.06	3.74	2.88	1.94	2.49
April	2.68	2.80	2.66	3.50	2.82	1.88	2.21
May	3.36	3.54	3.45	3.90	3.53	2.63	2.82
June	4.23	4.16	3.28	3.53	3.68	3.16	3.54
July	3.25	4.04	4.09	4.20	4.24	3.24	3.39
August	3.13	3.50	3.50	4.54	3.69	3.39	2.75
September	2.90	3.13	3.19	3.59	2.90	3.09	3.26
October	3.28	3.31	3.47	3.93	3.52	3.12	3.44
November	2.76	2.81	3.48	3.87	3.15	2.61	2.71
December	2.73	2.82	2.90	3.44	2.89	1.92	2.57
Annual	35.58	37.43	38.97	44.93	38.46	30.06	33.52
Storage period	16.03	16.49	17.96	21.29	17.27	11.44	14.43
Growing period	10.61	11.69	10.87	12.27	11.62	9.79	9.68
Replenishing period	8.94	9.26	10.14	11.37	9.57	8.83	9.41

a Average altitude of stations considered.

A study of the data shows that there are a number of contending forces which are distinctively operative in New York, and which by modifying one another tend to produce numerous irregularities of the rainfall. So irregular indeed is the precipitation that frequently places only a short distance apart show wide variations.

In a general way it may be said that the amounts of annual rainfall in different sections of New York are mainly determined by proximity to sources of vapor or to vapor-laden air currents, and by the character of the local topography. As regards the latter statement, a more definite form would be that under similar conditions the pre-

cipitation is in some degree proportionate to the altitude. This rule, while generally true, does not apply to the valley of Hudson River, where the upper portion, including the Champlain Valley, receives a somewhat deficient rainfall as compared with the State as a whole. To the west, the Adirondack Plateau receives a marked increase of rainfall, while farther northwest there is a decrease in the valley of the St. Lawrence. This is also true of the elevated region in the vicinity of Hemlock Lake, which, although several hundred feet higher, has a rainfall considerably less than that at Rochester.

In the southeastern portion of the State the ocean winds find no obstruction along the coast, but, passing inland and meeting the abrupt ranges of the southeastern counties, give a copious rainfall, as compared with that of the intervening regions.

Western New York, on account of the frequent southwesterly direction of the winds, receives an appreciable portion of its vapor supply from the Gulf of Mexico. The rainfall in central New York, although less than that of the southeastern and southwestern highlands, is generally abundant. The principal valleys of the Susquehanna system, and also the depression of the central lakes tributary to Oswego River, show a deficiency as compared with the average of the State.

A knowledge of the snowfall is important in a study of the water resources, because by reason of the snow lying on the ground continuously for several months it is a great source of loss in open regions subject to severe winds, the evaporative effect of the winds tending to carry away large quantities of moisture which would otherwise be available to maintain stream flow. Thus far the only data relating to depth of snow are those derived from the reports of the State meteorological bureau. The following are a few figures so derived: In the winter of 1891–92 the total depth of snow at Humphrey, in the Western Plateau, was 119.8 inches; in 1890–91 the total depth at Cooperstown, in the Eastern Plateau, was 110 inches; in 1891–92 the total depth at Constableville, in the Northern Plateau, was 170.7 inches; in the winter of 1890–91, at Utica, in the Mohawk Valley, the total depth was 165 inches, and in 1891–92, at the same place, 151.6 inches. The records show that at the places where these large snowfalls occurred the ground was continuously covered with snow for several months. If the winds were of high velocity at the same time the evaporation loss must have been very great.

ROCKS AND STREAM FLOW.

Among the principal factors affecting stream flow should be noted the structure and texture of the rocks, especially those of the surface. For example, in regions with stiff, heavy, compact soils a much larger proportion of the rainfall runs off on the surface, passing immediately into the streams, than is the case in regions with open, porous soils or extensive sandy areas. A general knowledge of the surface geology

is therefore desirable in a study of the water resources of the State. The relative position and area of the different geologic formations are best shown on the large geologic map of New York prepared under the direction of James Hall, State geologist, by W. J. McGee, and printed by the United States Geological Survey in 1894 (scale, about 5 miles to the inch). A similar but smaller map showing essentially the same features was also printed in the same year under authority of the regents of the university to accompany the report on the mineral exhibit of New York at the World's Columbian Exposition, this being on the scale of approximately 14 miles to an inch. On examining either of these maps one will note the preponderance, so far as area is concerned, of two classes of rocks—the ancient crystallines, which cover a large area in the northern part of the State, and the conglomerates, sandstones, and shales of the Devonian, which form the greater part of the Appalachian Plateau, stretching from Lake Erie across the State to within a short distance of Hudson River, this being the area classified by the State weather bureau as the Eastern and Western plateaus. The streams from the northern crystalline area undoubtedly furnish the best water supply of the State. This may not be due wholly to the character of the rocks, as many other factors contribute to this result.

The sandstones of the Upper Devonian along the northern boundary of Pennsylvania are bounded on the north by the long narrow belts of outcrop of the underlying rocks stretching in a general easterly and westerly direction. The streams pursuing a general northerly course pass in succession across these. As a rule, the soils of the region are heavy, with considerable clay, and the rainfall being absorbed somewhat slowly, a considerable portion of it flows directly into the water courses. The primeval forest has for the most part been cut away and heavy floods are common, such as those of the Genesee and Chemung rivers, described more fully on a later page.

The only streams of this region on which extensive discharge measurements have been made are Genesee River and its tributary, Oatka Creek. Streams of similar character in western Pennsylvania, however, have been measured for a number of years by the Philadelphia water department, and the results of these measurements are available for comparison and discussion. The results obtained on the Pennsylvania streams, the Neshaminy, Tohickon, and Perkiomen, are applicable particularly in estimates of the flow of the tributaries of Delaware River, rising in New York State, and to the more easterly streams which form the Susquehanna.

The drainage basins of the Oswego, Mohawk, and Hudson rivers are so highly composite as regards geologic formations and embrace such a wide variation in topography and surface geology that no definite deductions concerning the effect of the formations on water flow have been drawn. The streams of Long Island, rising among the sands,

tills, and gravels of comparatively recent, unconsolidated formations, offer peculiar conditions, which are discussed on a later page.

RIVER SYSTEMS.

The rivers of the State may be classified into seven general systems, whose relative position is shown by the accompanying index map, fig. 1. These are:

(1) St. Lawrence system, which includes all waters draining to Lakes Erie and Ontario, and Niagara and St. Lawrence rivers.

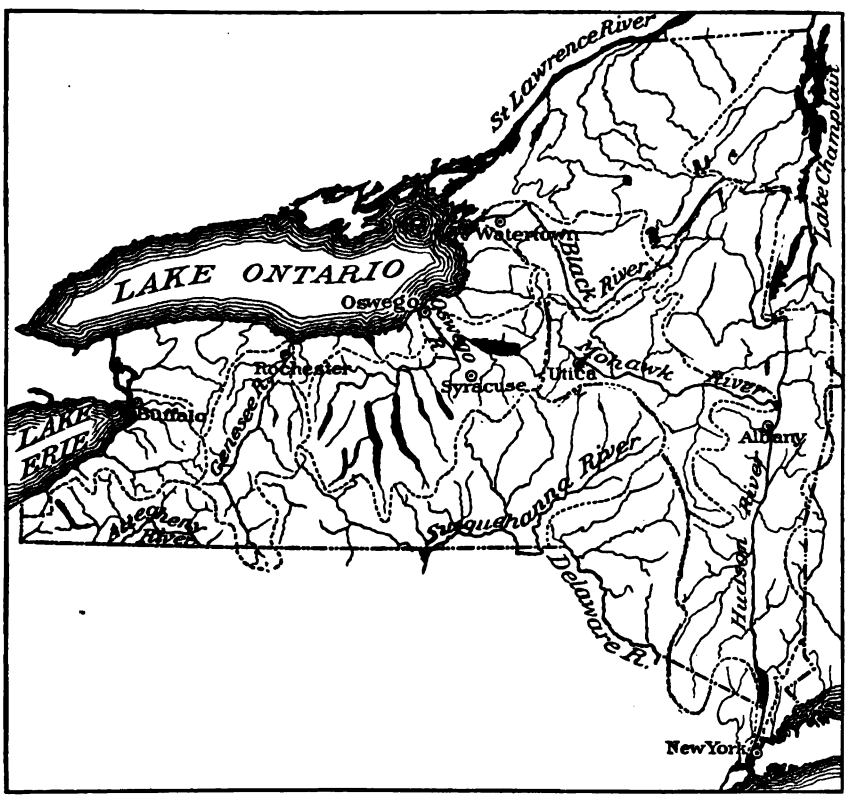


FIG. 1.—Index map of rivers of New York.

(2) Champlain system, including all streams in the State tributary to Lakes Champlain and George. The Champlain system is in reality a subdivision of the St. Lawrence, but made separate here merely for convenience in discussing the river systems of the State.

(3) Hudson River system, including all streams tributary to the Hudson and its main branch, the Mohawk.

(4) Allegheny River system.

(5) Susquehanna River system.

(6) Delaware River system.

(7) The streams of Long Island tributary to Long Island Sound and the Atlantic Ocean.

The head waters of the branches of Housatonic River in Connecticut flow out of the State to the east, while the head waters of Ramapo River, in Rockland County, flow from New York into New Jersey. These latter are of possible future importance by reason of the necessity of water for the supply either of Greater New York or, in the case of Ramapo River, also for the municipalities of northern New Jersey. Chateaugay River, a tributary of the St. Lawrence, also flows northward into the Dominion of Canada.

ST. LAWRENCE RIVER SYSTEM.

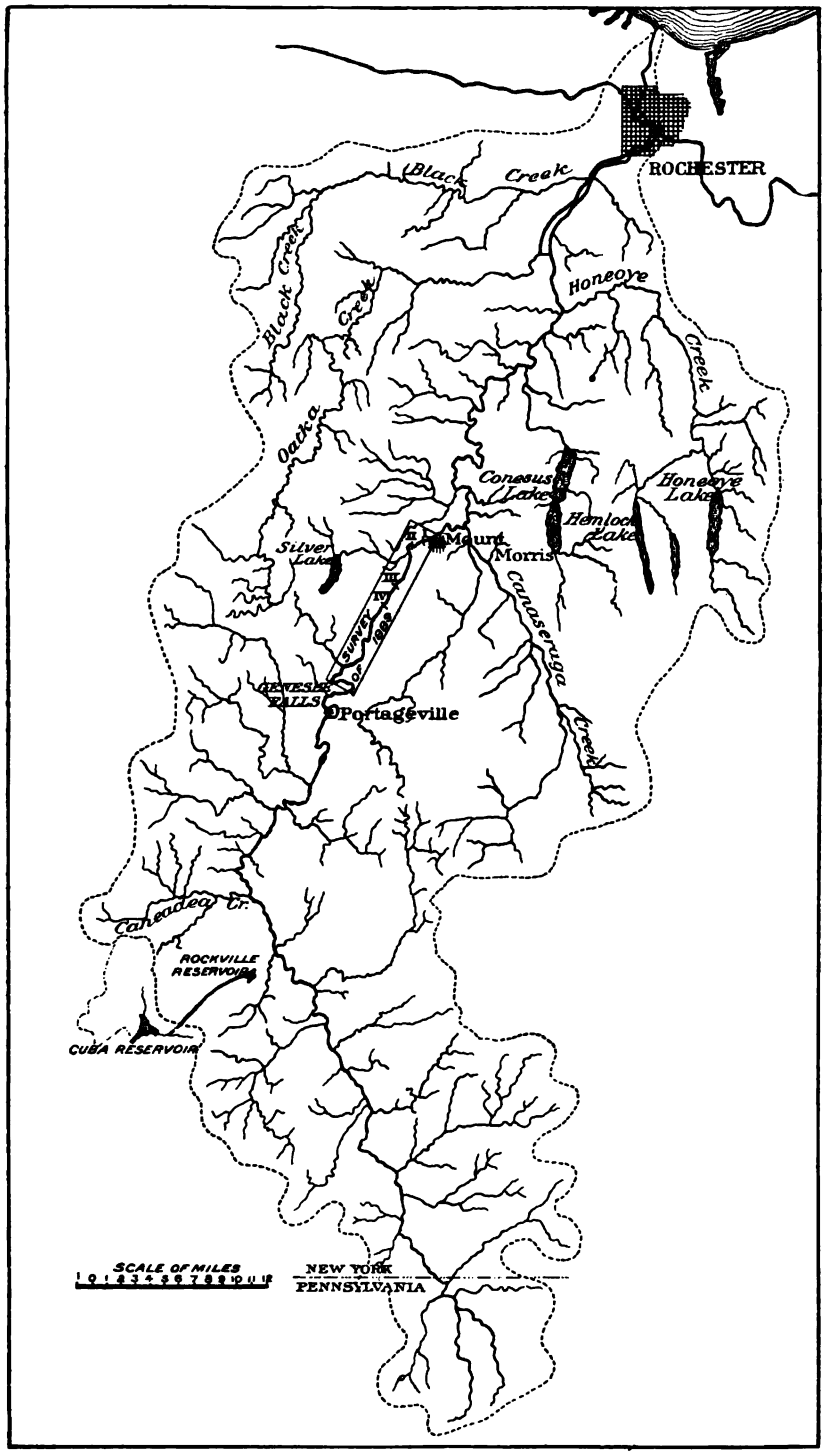
This group embraces the streams tributary to Lake Erie, Niagara River, Lake Ontario, and St. Lawrence River. On the extreme southwest, in Chautauqua County, the watershed line approaches within a few miles of Lake Erie, but at an elevation of several hundred feet above, and as a consequence the streams are short and rapid. A small amount of power is developed on Chautauqua Creek at Westfield, and on Canadaway Creek near Fredonia. Cattaraugus, Buffalo, Tonawanda, and Oak Orchard creeks may also be mentioned as tributaries of Lakes Erie and Ontario and Niagara River in western New York. Buffalo Creek is important as forming a large portion of Buffalo Harbor at its mouth. Tonawanda Creek, which flows into Niagara River at Tonawanda, is used for several miles as a part of Erie Canal. This stream is sluggish throughout nearly its whole course and affords only a small amount of power. The water supply of the village of Attica is taken from its head waters.

NIAGARA RIVER.

Niagara River forms a portion of the boundary between the Dominion of Canada and the State of New York. The difference in elevation between Lakes Erie and Ontario is, approximately, 336 feet, of which about 160 feet are at Niagara Falls. Between Lake Erie and Niagara Falls the river divides into two channels around Grand Island, which is 10 miles long and 4 or 5 miles wide. The general course of the river is from south to north, but in passing around Grand Island the eastern channel bends westward, and for 3 miles from the foot of the island the course of the river is west.

Goat Island lies at the foot of this westerly stretch. On the New York side the American channel finds its way around the island to the American Falls, which break over the rough ledge at right angles to the main river. The Horseshoe Falls, on the Canadian side, are about 3,000 feet higher up and lie between the west end of Goat Island and the Canadian shore. At the Canadian Falls the main river again turns to the north and pursues that general course to Lake Ontario.

The elevation of the water surface at the head of the rapids above the falls is 560 feet above tide water, thus giving a fall from the Lake



DRAINAGE AREA OF THE GENESEE RIVER.

Erie level to that point of from 12 to 13 feet, of which from 4 to 5 feet are included in the rapids at the city of Buffalo, in front of and just below Fort Porter. The descent in the river from the head of the rapids to the brink of the falls is about 50 feet. At the narrows, half a mile above the whirlpool, the elevation of the water surface is 300 feet, while that of the surface of the still water opposite Lewiston is 249 feet; the fall in this section, which is from 4 to 4.5 miles in length, may therefore be taken at 51 feet, while from Lewiston to the mouth at Fort Niagara the fall is only 2 feet in a distance of 7 miles. The total length of Niagara River is about 37 miles.

On account of the immense water-power developments now taking place at Niagara Falls the run-off of Niagara River must necessarily receive extended discussion in a complete account of the water resources of New York.

GENESEE RIVER.

Genesee River, as shown on Pl. III, issues from the highlands of the Allegheny Plateau in Potter County, Pennsylvania, a few miles south of the New York State boundary. Entering Allegany County, it first runs northwesterly for upward of 30 miles to near the village of Canadea, at which point it turns northeasterly, this direction being generally maintained to the mouth. It flows entirely across the county of Allegany and then for several miles forms the boundary between Livingston and Wyoming counties, after which it crosses the northeast part of Livingston into Monroe County, through which it continues to its mouth at Charlotte. Above Portage its course from the State line is chiefly through an alluvial valley.

From Portage to Mount Morris the river flows through a deep and in some places narrow canyon for a distance of over 20 miles. The Portage Falls, with a total descent including the intervening rapids of about 330 feet, are at the head of this canyon. The Upper Portage Falls have a descent, including the rapids, of about 70 feet. Half a mile below are the Middle Falls, shown on Pl. IV, with a descent of 110 feet; while 2 miles below begin the Lower Falls, consisting of a series of rapids about half a mile long with an aggregate fall of 150 feet. These three falls may be taken as aggregating about 270 feet, exclusive of the rapids. At present no power developments exist. Formerly a sawmill was located at the Middle Falls, but on account of the extinction of the lumber business on the stream it has not been operated for many years.

At Mount Morris, Genesee River issues into a broad, level, alluvial valley from 1 to 2 miles wide, which continues to near Rochester, where there is a descent of 263 feet in about 3 miles. The Upper Falls at Rochester, 90 feet in height, are a cataract in the Niagara limestone, while at the Lower Falls, 94 feet in height, shown on Pl. V, the Medina sandstone appears.

The principal tributaries of Genesee River are Canaseraga, Hone-

oye, and Conesus creeks from the east, and Oatka, Black, and Wiscoy creeks from the west. Honeoye, Canadice, and Hemlock lakes are tributary to the Honeoye Creek, and Conesus Lake to Conesus Creek. Silver Lake is another small body of water in the Genesee Basin and tributary to the river by the Silver Lake outlet. Canaseraga Creek joins Genesee River near Mount Morris. From Dansville to its mouth, a distance of 16 miles, this creek flows through a broad alluvial valley with very little fall. Above Dansville the stream is more rapid, but the comparatively small, deforested drainage area limits its value for water power. Honeoye Creek, which is the outlet of Honeoye, Canadice, and Hemlock lakes, furnishes some water power. There are also several mills on the outlet of Conesus Lake.

Formerly there were a number of mills on the Silver Lake outlet, but changed business conditions have led to their decay. The other tributaries of the Genesee have little significance as mill streams. It appears, then, that the two places of importance on Genesee River, from the water-power point of view, are Portage and Rochester. These will be discussed in detail farther on.

The following table gives the detail of the several subdivisions of the drainage area of Genesee River:

Drainage areas, in square miles, of tributaries of Genesee River.

Creek.	Drainage area.	Area above mouth.	Area below mouth.
Cryder	43.3	99.9	143.2
Chenunda	30.0	181.0	211.0
Dykes	68.3	214.0	282.3
Vandemarck	21.6	301.3	322.9
Knights	22.3	323.9	346.2
Phillips	32.3	372.8	405.1
Van Campens	55.7	410.4	466.1
Angelica	82.1	481.1	563.2
White	15.9	569.2	585.1
Black	31.1	595.5	626.6
Crawford	11.8	637.6	649.4
Caneadea	63.3	651.0	714.3
Cold	41.0	745.3	786.3
Rush	35.3	787.0	822.3
Wiscoy	108.6	833.6	942.2
Wolf	19.3	974.9	994.2
Silver Lake	30.4	1,029.2	1,059.6
Coshaqua	82.0	1,059.6	1,141.6
Canaseraga	258.7	1,148.4	1,407.1
Beards	41.3	1,423.1	1,464.4
Conesus Lake	88.8	1,555.5	1,643.9
Honeoye	262.6	1,675.9	1,938.5
Allens	198.1	1,947.1	2,145.2
Black	211.8	2,168.5	2,380.0

The total drainage area of Genesee River at its mouth is 2,445.6 square miles.

A. UPPER AND MIDDLE FALLS OF GENESEE RIVER AT PORTAGE.

B. GENESEE RIVER CANYON BELOW MIDDLE FALLS AT PORTAGE.

The following tabulation gives the elevation of Genesee River at various points.

Elevation above tide water of Genesee River at various points.

	Feet.
Mean surface of Lake Ontario	247
Crest of the feeder dam in south part of the city of Rochester	510
Low-water surface of river at New York, Lake Erie and Western Railway bridge near Avon	538
Crest of old Mount Morris power dam	605
Water surface just above Upper Falls at Portage	1,080
Water surface at New York, Lake Erie and Western Railway bridge near Belvidere	1,333

The extreme head waters in Potter County, Pennsylvania, are stated to be considerably over 2,000 feet above tide.

OSWEGO RIVER.

Oswego River flows into Lake Ontario at the city of Oswego. Its basin includes the more important of the inland lakes of western New York. Taking the lakes of the Oswego River Basin in order from west to east, their names, elevations above tide, area of water surface, and tributary drainage area at the foot of each lake are as follows:

Elevation and area of lakes of the Oswego River Basin.

Lake.	Elevation above tide.	Area.	Drainage area.
	Feet.	*Sq. miles.*	*Sq. miles.*
Canandaigua	687.0	18.6	175.0
Keuka	720.0	20.3	187.0
Seneca	443.0	66.0	707.0
Cayuga	380.0	66.8	1,593.0
Oswaco	710.0	12.4	208.0
Skaneateles	867.0	12.8	73.0
Otisco	784.0	3.0	41.0
Onondaga	364.0	4.0	267.0
Cazenovia	900.0	2.8	9.0
Oneida	370.0	80.9	1,300.0

The following are the drainage areas of Oswego River and its principal tributaries:

Drainage areas of Oswego River and principal tributaries.

	Sq. miles.
Oswego River at mouth	5,013
Below junction of Seneca and Oneida rivers	4,868
Oneida River	1,420
Seneca River	3,450

The subdivisions of the dainage area of Seneca River are as follows:

Subdivisions of drainage area of Seneca River.

	Sq. miles.
At junction with Oneida River	3,450
At Baldwinsville	3,136
At Montezuma	2,472
Below Cayuga Lake	1,593
At entrance to Cayuga Lake	780
At Seneca Falls	771
Waterloo	745
At foot of Seneca Lake	707
Keuka Lake Outlet	213
Catherines Creek	94

The drainage areas of Cayuga Lake and its tributaries are as follows:

Drainage areas of Cayuga Lake and tributaries.

	Sq. miles.
At outlet	813
Cayuga Inlet, including Cascadilla Creek	173
Fall Creek, not including Cascadilla Creek	152
Salmon Creek	90
Taughanic Creek	60

Clyde River, a tributary of Seneca River, is formed by the junction of Canandaigua Outlet and Mud Creek. The latter stream rises in the southern part of Ontario County and flows first north and then east, uniting with Canandaigua Outlet at Lyons. Clyde River joins Seneca River at Montezuma. The following are the drainage areas of Clyde River and tributaries:

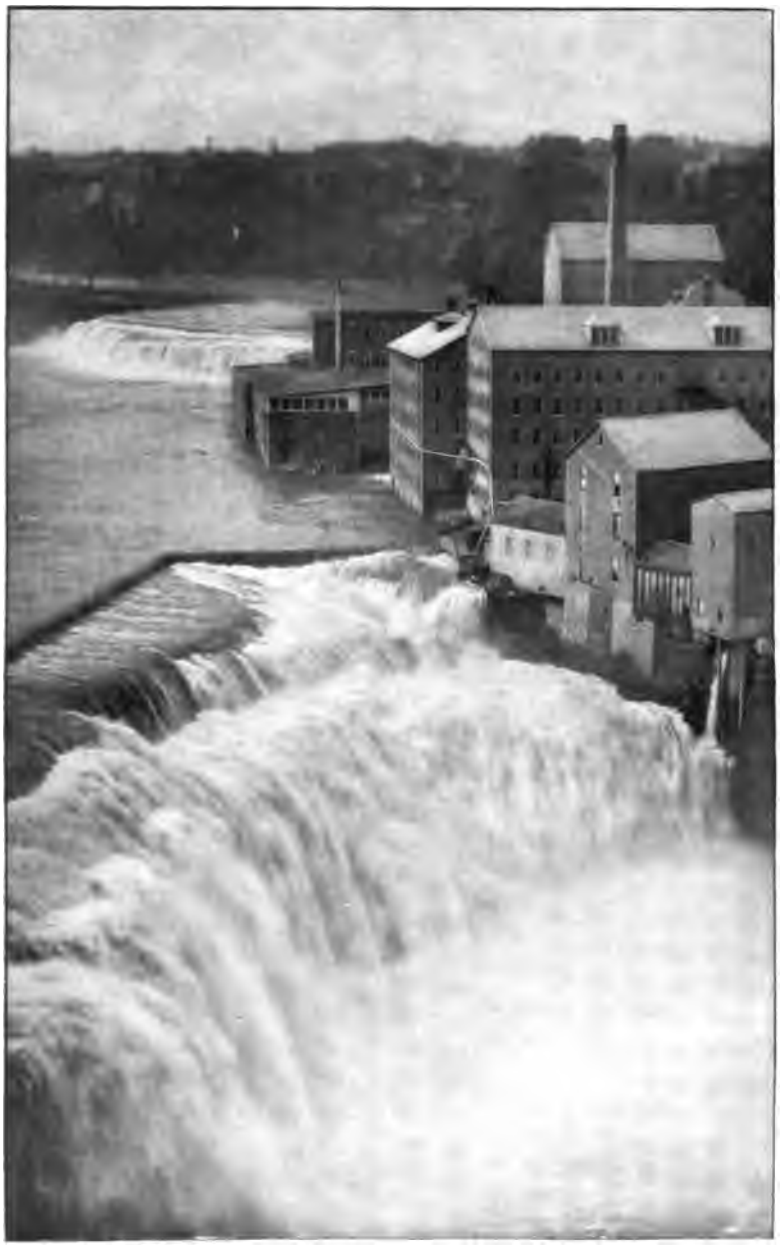
Drainage areas of Clyde River and tributaries.

	Sq. miles.
At mouth	869
At Clyde	807
At Lyons, at junction of Canandaigua Outlet and Mud Creek	729
Mud Creek at Lyons	298
Canandaigua Outlet at junction with Mud Creek	431
Canandaigua Outlet at Phelps	390
Canandaigua Lake at foot	175
Canandaigua Inlet	85

Owasco Lake discharges into Seneca River through an outlet 15 miles in length. The following are the drainage areas of Owasco Outlet:

Drainage areas of Owasco Outlet.

	Sq. miles.
At mouth	230
At Auburn	212
Owasco Lake at foot	208
Owasco Inlet	120



MIDDLE AND LOWER FALLS OF GENESEE RIVER AT ROCHESTER.

The drainage areas of Oneida River and its principal tributaries are as follows:

Drainage areas of Oneida River and principal tributaries.

	Sq. miles.
Oneida River at mouth	1,420
Oneida Lake at foot	1,300
Fish Creek	480
Chittenango Creek, including Cazenovia Lake	306
Oneida Creek	128

The Oswego River and its tributaries furnish a large number of water powers, the detail of which may be obtained from the Report on Water Power of the United States, Tenth Census of the United States, 1880. Very little can be added to the statements in that report.

The next stream of any importance tributary to Lake Ontario is Big Salmon River, which rises in the highlands of Lewis County and flows westerly into Lake Ontario. This stream was extensively considered several years ago as the source of water supply for the city of Syracuse, the water to be taken at a point about 40 miles distant from the city. Its watershed above the proposed point of diversion comprises 70 square miles of forest land at an elevation of from 1,000 to 1,500 feet above tide water.

BLACK RIVER.

Between Big Salmon River and the mouth of Black River there are a number of small streams flowing into Lake Ontario, none of which are of special importance. We may therefore pass to a brief description of Black River. This stream rises in the western part of Hamilton County and pursues a southwesterly direction, passing across Herkimer County into Oneida County; it then bends to somewhat west of north through Lewis County, but soon after passing the northwesterly boundary of that county it changes to a general westerly course, flowing into Black River Bay at the extreme eastern end of Lake Ontario. Extensive water-power developments are in use on this stream and its tributaries, at Watertown, Lyons Falls, Carthage, Black River, Brownville, Dexter, and other points. There are also a number of State reservoirs on the head waters which will be discussed in detail later. The following gives the elevation in feet of the main points on Black River above tide water, according to the best available information.

Altitude of points along Black River.

	Feet.
At mouth	247
Watertown, west line of city	370
Watertown at head of falls	492
Carthage at foot of rapids	669
Carthage at crest of State dam	724

Altitude of points along Black River—Continued.

	Feet.
Lyons Falls at foot	733
Lyons Falls, crest of State dam	802
Forestport, crest of State dam	1,129
North Branch reservoir	1,821
Chub Lake	1,599
Woodhull reservoir	1,854
South Branch reservoir	2,019
Moose River at mouth	802
First Lake, Fulton Chain	1,684
Second Lake	1,684
Third Lake	1,685
Fourth Lake	1,687
Fifth Lake	1,691
Sixth Lake	1,760
Seventh Lake	1,762
Eighth Lake	1,803
Little Moose Lake	1,772
Big Moose Lake	1,787
Beaver River at mouth	724
Beaver Lake at Number Four	1,436

The drainage areas of Black River and its tributaries, in square miles, are as follows:

Drainage areas of Black River and tributaries.

	Sq. miles.
Black River at mouth	1,860
At Watertown	1,820
At Carthage	1,741
At Lyons Falls below Moose River	810
Forestport	275
Above mouth of Sawmill Creek	174
Deer River	107
Beaver River	365
Lovell Creek	34
Independence Creek	90
Martins Creek	29
Otter Creek	60
Moose River	349
Sugar River	66

STREAMS FLOWING INTO ST. LAWRENCE RIVER.

Proceeding along St. Lawrence River we find a number of streams, such as the Oswegatchie, which flows into the St. Lawrence at Ogdensburg; the Grass, which enters the St. Lawrence near the north line of the State; the Raquette and St. Regis, flowing into the St. Lawrence a short distance below the Grass, and finally the Chateaugay, which flows from this State into the Dominion of Canada and thence into the St. Lawrence. These streams all head in and about the Adirondack Plateau and, as a rule, fall rapidly from their sources to near their mouths, affording large water powers, which thus far have

been chiefly utilized for pulp grinding, paper making, and sawing lumber.

There is a lack of definite information in regard to all the streams of the northern part of the State. No detailed surveys of this region have been made. Partial reservoir systems have been constructed on Oswegatchie, Grass, and Raquette rivers. Some of the economic questions involved in the construction of these reservoirs will be discussed in Part II of this paper, Water-Supply Paper No. 25.

So far as can be learned, no measurements have been made of any of the streams tributary to St. Lawrence River proper. It is probable, however, that they are the best water-yielding streams of the State, because they flow from the great northern forest, and because their head waters are in the extensive lake region which lies immediately west of the main Adirondack Mountains, and which extends westward from the base of the main range to the borders of the forest, a distance of nearly 50 miles. This portion of the Adirondack Plateau is comparatively level. As regards geographic distribution, these lakes are most numerous in the northern parts of Herkimer and Hamilton counties and the southern parts of St. Lawrence and Franklin counties. Those in Herkimer County flow into Moose and Beaver rivers, tributaries of Black River. The following are the elevations of a few of the more important lakes of Hamilton, St. Lawrence, and Franklin counties, which are tributary to streams flowing northward into the St. Lawrence:

Elevations of important lakes of Hamilton, St. Lawrence, and Franklin counties.

Lake.	Feet.
Cranberry	1,540
Raquette	1,774
Forked	1,753
Long	1,630
Little Tupper	1,728
Big Tupper	1,552

LAKE CHAMPLAIN SYSTEM.

Lake Champlain has a water area of 400 square miles. The area of its watershed in New York State amounts to 2,950 square miles, in Vermont to 4,270 square miles, and in the Province of Quebec to 740 square miles. The total area of watershed, not including water surface, is 7,960 square miles, or the total area of the drainage basin, including water surface, is 8,360 square miles. Lake Champlain is considered as beginning at Whitehall and terminating at St. Johns, on the Richelieu. Its length is 125 miles and its breadth in the

northern portion about 13 miles. The standard low-water elevation is given at 95.03 feet, and standard high water at 103.78 feet, above tide.

The streams tributary to Lake Champlain are Big Chazy, Little Chazy, Saranac, Salmon, Little Ausable, Big Ausable, and Bouquet rivers and the outlet of Lake George. There are also a few small streams of no special importance.

The streams tributary to Lake Champlain are, as a rule, not of great length, but rising, as they nearly all do, in or near the high mountains of the Northern Plateau they have a rapid descent with an abundant fall. For illustration we may refer to the Saranac River, which has, by the county maps of Bien's Atlas, a length of about 55 miles from its mouth to Lower Saranac Lake. The elevation of Lake Champlain above tide water is 101 feet, while that of Lower Saranac Lake is given at 1,539 feet. Hence the fall in 55 miles of river course is 1,438 feet. Middle Saranac Lake lies at an elevation of 1,542 feet and Upper Saranac at 1,557 feet.

In the case of Ausable River we find a distance by the course of the river of about 40 miles from its mouth to Lake Placid, the elevation of that body of water being 1,864 feet above tide, or 1,763 above Lake Champlain; or, taking the distance by that fork of Ausable River which leads to Ausable Lakes, the distance is about 42 miles to Lower Ausable Lake, the elevation of which is 1,961 feet above tide; hence we have a fall in this stream of 1,860 feet in a little over 40 miles. The water power of the several streams tributary to Lake Champlain has been extensively developed at Plattsburg and other points, as indicated by the tabulations relating to pulp, paper, and lumber interests.

The most southerly tributary of Lake Champlain of any importance for water purposes is the outlet of Lake George, which in about 2 miles has a fall of 222 feet. The greater portion of this is concentrated in the first mile from the lake. The elevation of Lake George above tide water is 323 feet. The area of the lake surface is stated at 50 square miles, and the tributary drainage area above the foot of the lake at 238 square miles. In the absence of accurate topographic maps the drainage area of Lake George, like that of most of the other streams considered, can be given only approximately.

As will be shown later, the streams in eastern New York can not be depended on to furnish a natural flow of more that about 0.3 cubic foot per square mile per second as a minimum in a dry year. On account of the large water surface of Lake George in proportion to the drainage area, it is possible, by utilizing the storage on the lake surface, to realize a much larger quantity. From 0.7 to 0.8 cubic foot per second per square mile may be assumed as a conservative estimate, the results being based on allowing the water to flow out of the lake 24 hours per day for only 310 days in the year. On this

basis we may assume a mean flow for minimum dry years of about 200 cubic feet per second. Since the entire 222-foot fall of the Lake George Outlet is now utilized, we may place the permanent power in a dry year at about 5,000 gross horsepower. The village of Ticonderoga, at which this power is all utilized, had a population in 1890 of 2,267.

Wood Creek, the most southerly tributary of Lake Champlain, is of interest in a study of the water resources of New York, chiefly because of its relations to Champlain Canal, its channel being utilized for several miles as part of the canal. At Fort Ann there is considerable power developed on one of its tributaries, used at present for grinding pulp.

HUDSON RIVER SYSTEM.

Hudson River, with its principal tributary, the Mohawk, is the most important river of the State. From its mouth to Troy, a distance of over 150 miles, it is a great inland estuary subject to tidal action, and because of its great length and the large fresh-water inflow it is unique among inland estuaries. From the first landing of the Dutch on Manhattan Island to the present time it has been an important channel of commerce. On his voyage of discovery in 1609, Hendrik Hudson ascended to the head of tide water, and doubtless discerned the possibilities of future settlement which were so soon realized at Albany, Waterford, and Schenectady. The tidal action of Hudson River originally terminated at the rapids above Troy, but its present termination is a few miles below, at the Troy dam, a structure erected about 1820 as a part of the State canal system. There is a lock at the east end of this dam through which canal boats pass into the pool above, thus enabling them to reach Lansingburg on the east side of the river, or Waterford on the west side, where they may enter Champlain Canal.

Below Troy the tributaries of Hudson River are mostly small and generally not of very great importance, although some of them have considerable power development. One of them, Croton River, is the principal source of water supply of the city of New York. On this part of the river the drainage basin is rather narrow, and many of the streams issuing from the highlands at either side have such small drainage areas as to carry only moderate quantities of water. In descending the river from Troy the principal streams are, on the west side, Normankill, Catskill, Esopus, and Rondout creeks, and on the east side Kinderhook, Wappinger, and Fishkill creeks and Croton River. Harlem River, connecting the Hudson with East River, may be mentioned, in view of its value to navigation interests, as an important feature of the water resources of New York.

The following are the elevations of mean tide, mean low tide, and mean high tide above mean sea level at New York, and the mean rise

and fall of tides at various points along the tidal estuary between New York Bay and the Troy dam:

Mean tidal elevations in feet at various points between New York Bay and Troy dam.

Locality.	Mean tide.	Mean low tide	Mean high tide.	Mean rise and fall.
Sandy Hook				4.70
Governors Island	0.00	2.20	2.20	4.40
Dobbs Ferry	0.18	1.62	1.98	3.60
Coxsackie light-house	1.68	0.17	3.53	3.70
New Baltimore	1.73	0.02	3.44	3.42
Colymans	1.88	0.44	3.31	2.87
Castleton	2.09	0.82	3.35	2.53
Van Wies	2.13	0.82	3.29	2.33
Albany	2.43	1.27	3.59	2.32
Nail works	2.78	1.81	3.75	1.94
Troy dam	3.77	3.37	4.17	0.80

The most important tributaries begin above Troy. Ascending on the west side we find Mohawk River, the outlet of Saratoga Lake, Sacundaga River, Stony and North creeks, and Indian and Cedar rivers. On the east side there are Hoosic, Battenkill, Schroon, and Boreas rivers. Above the mouth of Cedar River the main North or Hudson River is considered to extend to and beyond Lake Sanford, including Opalescent River and the streams issuing from the high Adirondacks.

The following gives the height above tide water at New York of a number of points on Hudson River.

Height above tide water at New York of points on Hudson River.

	Feet.
New York (at mouth)	0.0
Troy	3.8
Saratoga dam (crest)	102.0
Fort Edward (below dam)	118.0
Glens Falls (crest of feeder dam)	284.0
Mouth of Sacundaga River	556.0
Mouth of Stony Creek	584.0
Mouth of Schroon River	608.0
At Glen Bridge	728.0
At Riverside Bridge	875.0
At North Creek Bridge	998.0
At North River	1,050.0
Mouth of Boreas River	1,140.0
Mouth of Indian River	1,415.0
Mouth of Cedar River	1,460.0
Lake Sanford	1,723.0

MOHAWK RIVER.

Mohawk River, the most important tributary of the Hudson, rises in the western-central part of the State, near the Lewis and Oneida county line. It flows in a southerly direction to the city of Rome, from which it takes an easterly course across the State, emptying into the Hudson a little above Troy. The principal tributaries are Schoharie, East Canada, West Canada, and Oriskany creeks.

The following are the elevations above tide water of a number of points along Mohawk River:

Elevations of points along Mohawk River.

	Feet.
At mouth	12
Lower Mohawk Aqueduct	162
Schenectady	214
Mouth of Schoharie Creek	270
At Rome, above feeder dam	431

There are two principal falls of Mohawk River, the Great Falls at Cohoes and the Little Falls at the city of the same name, where are found the only important water powers thus far developed on this stream. At Cohoes are the Great Falls, about 120 feet in height, on which the Cohoes Company has developed about 105 feet. At Little Falls there is a total fall of about 45 feet occurring in a little over half a mile. Of this, from 38 to 40 feet are utilized by three dams. Aside from a small amount of power developed below Cohoes, just above the "sprouts" of the Mohawk, there are no water-power developments on the stream other than those of Cohoes and Little Falls, except a few unimportant mills on the extreme head waters. The waterworks of the city of Rome, at Ridge Mills, 2 miles north of Rome, where a water-power pumping system is in use, may, however, be mentioned.

The following are the principal subdivisions of the drainage areas of Mohawk River:

Subdivisions of drainage area of Mohawk River.

	Sq. miles.
At mouth	3,400
Below mouth of Schoharie Creek	3,100
At Little Falls	1,275
At Utica	524
At Rome	184

SCHOHARIE CREEK.

Schoharie Creek rises in the southern part of Greene County, whence it flows 18 miles northwesterly and then northerly about 50 miles to the Mohawk. The principal subdivisions of the drainage area are as follows:

Subdivisions of drainage area of Schoharie Creek.

	Sq. miles.
At mouth	947
Central Bridge	684
Gilboa	308

The drainage area of Schoharie Creek comprises the greater part of Schoharie County and portions of Greene, Albany, Delaware, Otsego, Montgomery, and Schenectady counties. Its head waters drain the western and northern slopes of the Catskill Mountains. At Central Bridge, about 19 miles from the mouth of the creek, the water surface is 560 feet above tide water; at the mouth the elevation is 274 feet. In spite of this large fall Schoharie Creek is not considered especially valuable for water-power development. It is subject to great extremes of flood and low-water flow. This is probably explainable by the nearly complete cutting off of the forests from the drainage area many years ago. The water powers thus far developed in the Schoharie Creek Basin are nearly all small and unimportant.

EAST CANADA CREEK.

The second important tributary of the Mohawk is East Canada Creek, which rises in the southwestern part of Hamilton County and flows southerly, joining the Mohawk at East Creek, about 7 miles from Little Falls. According to a map furnished by Stephen E. Babcock, of Little Falls, the total drainage area of East Canada Creek is 285.7 square miles, of which 58.2 square miles are in Hamilton County, 98.4 square miles in Herkimer County, 128 square miles in Fulton County, and 1.1 square miles in Montgomery County. Following are the elevations of principal points on East Canada Creek:

Elevations of principal points on East Canada Creek.

	Feet.
Bottom of Beardslee Falls near mouth	0
Top of Beardslee Falls	105
Bottom of High Falls	327
Top of High Falls	379
Crest of dam at Dolgeville	445
Mouth of Spruce Creek	477
Mouth of Fish Creek	559
Emmonsburg	646
Stratford	720
Oregon	1,140

The distance from the mouth of the stream to Oregon is about 25 miles.

The principal tributary of East Canada Creek is Fish Creek, which is the outlet of the East Canada lakes. The distance from its point of junction with East Canada Creek to the mouth of the Canada lakes outlet is about 9 miles, and the total rise in this distance 635 feet. The outlet of the lakes, which is nearly level, is about 3.5 miles long. There are no falls of any magnitude on this creek. For the first 5 miles from its mouth Fish Creek rises 245 feet, and from that point to the mouth of the outlet of the East Canada lakes, a distance of 4 miles, the rise is 390 feet.

The second tributary of East Canada Creek is Spruce Creek, which has a total length from its mouth to its head in the Eaton Millpond of about 8.7 miles, the total rise in this distance being about 550 feet. Just below the Eaton Millpond there is a fall of 180 feet in 2,000 feet. At Salisbury Center, Spruce Creek falls 85 feet in about 900 feet. Aside from the development at Dolgeville, and small developments at Beardslee Falls and at one or two other points, very little use has thus far been made of the water power of East Canada Creek. It is probable, however, that within a few years the water power of this stream will be nearly all utilized.

According to a manuscript report on the water power of East Canada Creek, by S. E. Babcock, the fall in this stream for the first 1,500 feet from its junction with Mohawk River is very slight. At this point the first rapids are encountered, where it has been proposed to develop a water power, with a head of about 60 to 70 feet. About 1,000 to 1,200 feet farther upstream there is an additional fall of from 30 to 40 feet. This takes us to the top of the so-called Beardslee Falls, referred to above.

It has also been proposed to construct an extensive system of power development by a series of dams on East Canada Creek, some of the details of which may be gathered from the following table:

Plan of power development on East Canada Creek.

Location.	Head (in feet).	Horse-power.	Estimated cost.	Cost per horse-power.
Twin Bridges	43	1,172	$108,427	$92.51
Green street	26	1,023	73,667	72.01
Factory	29	1,141	30,910	27.10
Intermediate	22	865	46,090	53.28
High Falls	72	2,700	56,320	20.86
No. 1 (below High Falls)	74	2,956	125,092	42.40
No. 2 (below High Falls)	34	1,360	56,408	41.40
No. 1 (Ingham's mill)	44	1,778	135,410	76.16
No. 2 (Ingham's mill)	44	1,778	129,800	73.00
Beardslee Falls	105	5,112	128,326	25.10
Totals and mean	423	19,885	890,450	44.80

This plan of power development further includes the construction of a storage of 1,250,000,000 cubic feet, which is estimated to cost $148,000, making a total for the whole development of $1,038,450. With these figures the final cost per net horsepower becomes $52.22. The estimates leading to this result include cost of land to be flooded, masonry of dams and head works, turbine water wheels, flumes and head feeders, tail raceways, waste gates, power stations, racks, engineering

ing into the Mohawk at the village of Herkimer. The total drainage area above Herkimer is given as 548 square miles. This creek has its source in the Canada lakes, which are about 40 miles northeast from the village of Prospect. These lakes are known separately as the West, Middle, and East Canada. The principal lake of this series has an elevation of 2,348 feet above tide water. The drainage area at the village of Prospect, where there is a natural fall of about 22 feet, is 375 square miles. At Trenton Falls, 3 miles below, the stream descends about 200 feet in half a mile. Ascending the stream, the principal falls, in order, are: Sherman Falls, 24 feet; High Falls (shown in Pl. VI), 105 feet; Mill Dam Falls, 14 feet; Suydam Falls, 12 feet.

According to a report made by Wallace C. Johnson, under date of March 17, 1896, to the Trenton Falls Power Company, it appears that of the 375 square miles of drainage area above Prospect about 175 square miles lie at an elevation of between 2,000 and 3,000 feet above tide water, the average elevation of this portion being about 2,500 feet. Of the remaining 200 square miles above Prospect the average elevation is placed at not less than 1,600 feet. The Trenton Falls Power Company is reported as intending to develop an extensive storage on the head waters of this stream, thus enabling it to produce several thousand electrical horsepower at Trenton Falls for transmission to Utica, Rome, and other towns in the vicinity. General plans have been prepared by Mr. Johnson, but the details of the project are not at hand. Judging from the data at hand, the author is disposed to place the minimum flow of West Canada Creek at from 0.30 to 0.35 of a cubic foot per square mile per second.

Water powers are now in use on West Canada Creek at Herkimer, Middleville, Newport, and Prospect, as well as at a few points higher up.

Parties interested in the development of an extensive power project at Trenton Falls have claimed that a very large storage reservoir could be constructed in the main valley of West Canada Creek a short distance above Prospect, and at very low cost per unit volume stored. The data are not at hand for accurately determining the cost of a reservoir at this place. However, casual inspection of the Remsen sheet of the topographic map of the State, made in 1897, shows that such a reservoir would probably be expensive in proportion to the storage gained. A trial estimate shows that with a dam from 80 to 100 feet in height a storage of about 2,000,000,000 cubic feet may be obtained. The cost of the dam necessary to store this quantity of water can hardly be placed as an experimental figure at less than $1,000,000, whence the cost per 1,000,000 cubic feet stored would become $500. This approximate estimate has no other significance than to indicate the importance of studying large reservoir projects in detail before deciding as to their feasibility.

OTHER TRIBUTARIES OF MOHAWK RIVER.

As less important tributaries of the Mohawk, Sauquoit and Oriskany creeks may be mentioned. Sauquoit Creek rises in the southeastern part of Oneida County and runs northerly, emptying into the Mohawk about 2 miles west of Utica. Its drainage area is given as 62 square miles. Oriskany Creek rises in the eastern-southerly portion of Madison County and flows northerly into the Mohawk 6 miles west of Utica. Its drainage area is given as 135 square miles. There is considerable water power developed on both Sauquoit and Oriskany creeks.

HOOSIC RIVER.

The most important tributary of the Hudson from the east is Hoosic River, which rises in the mountains of Berkshire County, Massachusetts. It first runs northwesterly, passing from Massachusetts into the extreme southwestern corner of Vermont and thence into Rensselaer County, in New York. At the northern boundary of Rensselaer County it turns and pursues a westerly course to the Hudson opposite the village of Stillwater. Its drainage area at the mouth is taken at 730 square miles. Its principal tributaries are Little Hoosic River, Walloomsac River, and Tomhannock Creek. The country drained is mainly mountainous, the summits attaining an elevation of from 1,000 to 2,000 feet above tide. The principal water powers developed on Hoosic River, in New York, are at Schaghticoke and Hoosic Falls, with a few at intermediate points. At Schaghticoke there is from 97 to 98 feet fall, broken into falls of 8, 7.5, 24.5, 34.5, and 23 feet. The available statements as to the power at Hoosic Falls are so conflicting that it is thought best to omit them.

Hoosic River is of considerable interest to persons concerned in water-power development on the Hudson below its mouth, because there are two reservoirs on its headwaters which have been constructed by manufacturers in Massachusetts in order to maintain a more equable summer flow. The first of these is the Clarksburg reservoir, on the North Branch of Hoosic River, and at a distance of about $2\frac{1}{2}$ miles above North Adams. The second reservoir is on the South Branch, and is known as the Cheshire reservoir, being situated in the town of that name. The Clarksburg reservoir is stated to flow 156 acres and to have a depth of 22 feet. The Cheshire reservoir flows about 650 acres and can be drawn down about 8 feet. Both these reservoirs are controlled by an association of mill owners on the Hoosic and its branches in the State of Massachusetts.

BATTENKILL RIVER.

Battenkill River, another important tributary of the Hudson, rises in the southwestern part of Vermont, in Bennington County. It first

BIG FALLS OF BATTENKILL RIVER.

flows southwesterly and then westerly irregularly across Washington County, New York, to the Hudson at a point about a mile above Schuylerville. The drainage area is taken at 460 square miles. The elevation above tide at the mouth of the river is 82 feet, and at the Delaware and Hudson Railway crossing, a little south of Shushan, the elevation is 437 feet. This gives a descent of 355 feet in 22 miles, about one-half of which is concentrated within the last 4 or 5 miles of the river's course.

The following is a brief statement of the water powers on the lower section of the Battenkill, in ascending order from the mouth:

Water powers on the lower section of the Battenkill.

At Clark Mills, the American Woodboard Company, 24 feet head.

At Big Falls (shown on Pl. VII), the dam at the head of the falls gives 106 feet head, divided into Bennington Falls Pulp Company, 32 feet; Ondawa Pulp and Paper Company, 30 feet; not utilized, 44 feet.

At Middle Falls, the dam at the head of the falls gives 55 feet head. Here there are a leather-board mill, shank mill, sawmill, plaster mill, gristmill, and electric-light station.

At Greenwich, Dunbar, McMaster & Co., 8 feet head; Palmer's lower dam, 9 feet head, furnishes power for gristmill, paint works, shirt manufacturing, scale manufacturing, and plow works; Palmer's upper dam, 6 feet head, furnishes power for a cotton mill and a paper mill.

At Center Falls, Angel & Langdon Paper Mill, 25 feet head.

At Battenville, Phœnix Paper Company, 10 feet head.

At Rexleigh there is a cotton mill with 6 feet head; at Shushan a gristmill, shirt factory, electric-light station, and foundry, all receiving power from about 14 feet head.

In addition to the foregoing there are stated to be undeveloped water powers on the Battenkill as follows: Between Clark Mills and Big Falls, 27 feet; between Greenwich and Center Falls, 8 feet; between Center Falls and Battenkill, 10 feet.

It is stated that the utilized powers on the Battenkill are developed up to about 30 horsepower per foot fall. They are, however, sometimes short of water in dry weather. With a drainage area of 460 square miles, a minimum flow of 0.3 of a cubic foot per square mile per second would give only about 15.3 gross horsepower per foot of fall. It is inferred, therefore, that the Battenkill is an exceedingly good water yielder, although definite data derived from stream measurements are entirely lacking.

FISH CREEK.

Fish Creek, a stream tributary to the Hudson at Schuylerville, is the outlet of Saratoga Lake. Its chief tributary is the Kayaderosseras Creek, which drains the central part of Saratoga County. The drainage area of Fish Creek at its junction with the Hudson is estimated at 253 square miles. Both Fish Creek and Kayaderosseras Creek are extensively utilized for water power.

SACUNDAGA RIVER.

Sacundaga River, a view of which is given on Pl. VIII, is the next important tributary of the Hudson in the ascending order. It has three principal branches, which unite to form the main river in the southeastern part of Hamilton County. The West Branch is the outlet of Piseco Lake; the Middle Branch is the outlet of Sacundaga and Pleasant lakes, while the East Branch issues from a series of small ponds and lakes in the southwestern part of Warren County, not far from Bakers Mills. The East and Middle branches unite a few miles to the north of Wellstown, and West Branch joins a few miles south of Wellstown. The river then flows southeasterly to about 5 miles below Northville, where it turns rather more than a right angle and flows irregularly northeast to the main Hudson at Hadley. The principal tributary of the Sacundaga, aside from its several branches, is East Stony Creek.

The following are the several subdivisions of the drainage area of Sacundaga River:

Subdivisions of the drainage area of Sacundaga River.

	Sq. miles.
Total drainage area at mouth	1,040
South Branch	240
Middle Branch	115
East Branch	124
Stony Creek	212
Main river below Stony Creek	223

The following are elevations above tide at a number of principal points:

Elevations above tide of points along Sacundaga River.

	Feet.
At mouth of river	556
Above dam at Conklinville	697
Northville	732
Hope Center	763
Wellstown	902
East Branch at old tannery	958
East Branch at foot of High Falls	1,205
East Branch at head of High Falls	1,337
East Branch at Brighams Pond	1,706
Piseco Lake	1,648
Lake Pleasant	1,706
Sacundaga Lake	1,706

From Conklinville to the mouth of the river, a distance of a little over 5 miles, the river falls 141 feet. At present this section of the river is entirely unutilized except by two powers, one at Conklinville and the other about 2 miles from Hadley.

Thus far there are no detailed measurements of the Sacundaga, but since the drainage area is still largely in primeval forest it is without doubt an excellent water yielder.

A. HUDSON RIVER ABOVE LUZERNE

B. SACUNDAGA RIVER NEAR LUZERNE.

SCHROON RIVER.

Schroon River rises in Essex County, along the southern slopes of the highest mountains of the Adirondack group. As shown by the map (Pl. IX), it flows in a general southerly direction for about 45 miles, through Essex and Warren counties, and joins the Hudson just above Thurman. On the boundary between Essex and Warren counties the river flows through Schroon Lake, a body of water nearly 9 miles long and from a little less than 0.5 to 1.5 miles in width.

The following are some of the important subdivisions of the drainage area of Schroon River:

Subdivisions of the drainage area of Schroon River.

	Square miles
At mouth	550
Warrensburg	535
Tumblehead Falls	502
Foot of Schroon Lake	479

Some of the elevations on Schroon River are as follows:

Elevations on Schroon River.

	Feet.
At mouth	610
Schroon Lake	807
Paradox Lake	820
Schroon Falls	840
Elk Lake	1,986

There is no developed water power on Schroon River except that at Warrensburg.

TRIBUTARIES SOUTH OF MOHAWK RIVER.

Kinderhook Creek and Croton River are the chief tributaries of the Hudson south of the Mohawk requiring special mention at this time. Brief consideration of the run-off of Croton River will be given further on. The Columbia Electric Light Power Company, of Valatie, was incorporated by the laws of 1897 to construct reservoirs and create extensive power developments on Kinderhook Creek and its tributaries in Columbia and Rensselaer counties. The surveys for this work are now in process under the direction of L. L. Tribus, chief engineer of the company.

Wallkill River, a branch of Rondout Creek, may be mentioned. This stream rises in New Jersey and flows north, joining Rondout Creek near Rondout. It is proposed to take an additional water supply for Brooklyn Borough of Greater New York from the head waters of this stream in New Jersey. The drainage area south of the New York State line is 210 square miles.

ALLEGHENY RIVER SYSTEM.

The Allegheny River enters the State of New York from Pennsylvania in the southeastern corner of Cattaraugus County and, flowing in nearly a semicircle with its outward curve to the north, passes out of the State in the southwestern part of Cattaraugus County, again entering Pennsylvania. Its principal tributary from the north is Conewango Creek, which receives the outlet of Chautauqua Lake and of Cassadaga Creek as tributaries. Little Valley, Great Valley, and Olean creeks are also tributaries in New York. None of these streams is of especial importance for water power.

Chautauqua Lake, 20 miles in length and from 1 to nearly 2 miles in width, is distant from Lake Erie at its northern extremity only about 9.5 miles. Its elevation above tide water is 1,297 feet, while that of Lake Erie is 573 feet. Hence Chautauqua Lake is 724 feet above Lake Erie. The Conewango Creek, at the south line of the State, has an elevation of 1,243 feet. The fall from Chautauqua Lake to the southern boundary of the State along the drainage line is therefore only 54 feet. The drainage area of the Chautauqua outlet at the foot of Chautauqua Lake is 178 square miles, and of the Chautauqua outlet below Cassadaga Creek 343 square miles.

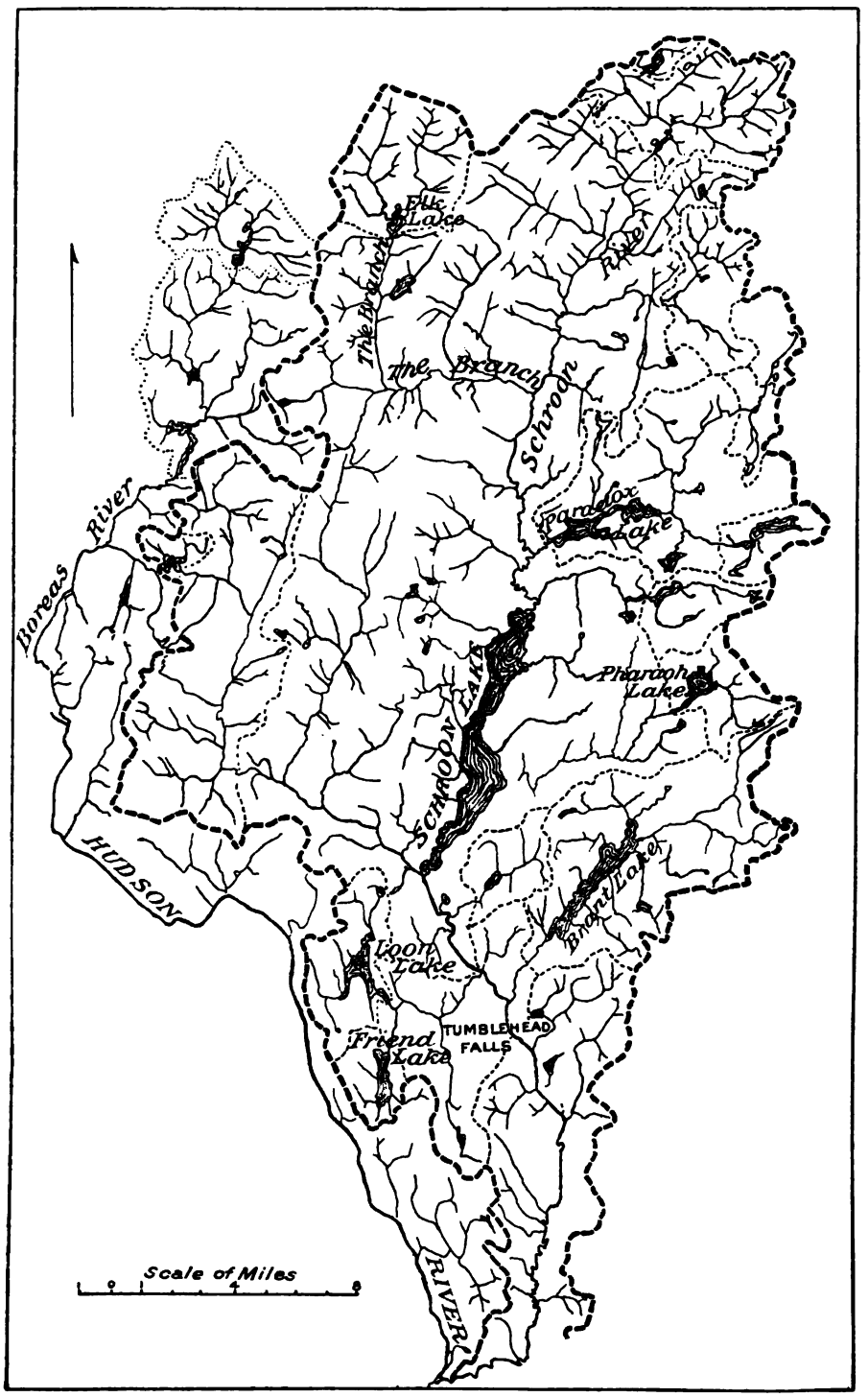
SUSQUEHANNA RIVER SYSTEM.

The head waters of the North Branch of Susquehanna River lie chiefly in the State of New York, the drainage area in this State being taken at 6,267 square miles. The main stream is considered as rising in Otsego Lake, from which it flows first southwesterly, then westerly with a short portion of its course south of the Pennsylvania line. It finally leaves New York State in Tioga County. The Susquehanna, while one of the large rivers of New York, is not at all important as regards water power. The main river and most of its tributaries in New York flow through a rolling country with fairly uniform declivity. While utilized for small powers in many places, thus far there are no extensive developments on either the main stream or its branches, except at Binghamton, where considerable water power is utilized. The slope of the stream in New York State is shown by following elevations, in feet, above tide water:

Elevations along Susquehanna River in New York State.

	Feet.
At Towanda, a few miles south of the State line	700
At Athens, on Chemung River, near the State line	744
At Otsego Lake	1,193

So far as known, no discharge measurements of this stream have ever been made.



DRAINAGE AREA OF SCHROON RIVER.

As one of the important tributaries of the North Branch of Susquehanna River in New York may be mentioned Chenango River, which rises in Madison County, and flows south through Madison, Chenango, and Broome counties, emptying into the Susquehanna at Binghamton. Chemung River, the chief tributary of the North Branch, is formed in Steuben County, New York, near Painted Post, by the junction of the Tioga and Cohocton Rivers, whence it pursues a southeasterly course, joining the Susquehanna near Athens, in Bradford County, Pennsylvania, just south of the State line. Tioga River rises in Tioga County, Pennsylvania, and flows north to join the Cohocton at Painted Post. Canisteo, the principal New York State tributary of the Tioga, joins the main stream 5 miles south of Painted Post. Cohocton River, which rises in Livingston County, and flows southeast to join the Tioga at Painted Post, is utilized for small powers at a number of places. The area drained by the Cohocton and Canisteo is almost entirely denuded of forest and the streams are in consequence much less valuable for power than formerly. For a considerable length of time, in the fall of 1895, the natural yield of these streams was probably considerably less than one-tenth of a cubic foot per second per square mile.

Other tributaries of the Susquehanna in New York State are Owego and Cuyuta creeks, neither of which, although formerly extensively utilized for small powers, is now of great value, largely because of the exceedingly slight summer flows.

The following are the drainage areas of the Susquehanna and its tributaries in the State of New York:

Drainage areas of Susquehanna River and its tributaries in New York.

	Square miles.
Main river below mouth of Chemung River (south of Pennsylvania line)	7,463
Total area north of Pennsylvania line	6,267
Above mouth of Chemung River	4,945
At Binghamton	2,279
At Susquehanna	2,024
At Nineveh	1,789
Below mouth of Unadilla River	1,638
Below mouth of Oak Creek	212
Above mouth of Oak Creek	97
Oak Creek	115
Cherry Valley Creek	121
Chenevas Creek	127
Charlotte River	178
Otego Creek	106
Oaliout Creek	115
Unadilla River	561
Butternut Creek	123
Chenango River at mouth	1,540
Chenango River above Tioughnioga	685
Chenango River above Canasawacta Creek	297
Tioughnioga River at mouth	735

Drainage areas of Susquehanna River and its tributaries in New York—Cont'd.

	Square miles.
Tioughnioga River above mouth of Otselic River	428
Otselic River	259
West Branch of Tioughnioga River	103
East Branch of Tioughnioga River	164
Owego Creek	391
Cayuta Creek	148
Chemung River at junction of Canisteo and Cohocton rivers	1,941
Chemung River at Elmira	2,055
Chemung River at mouth	2,518
Cohocton River at mouth	425
Tioga River at mouth	1,530
Tioga above mouth of Canisteo	750
Canisteo at mouth	780
Tuscarora Creek at mouth	120

DELAWARE RIVER SYSTEM.

The extreme head waters of Delaware River, in New York, are a series of small ponds in Schoharie County, a little north of the village of Stamford. From this point the stream flows southwesterly to Deposit, on the line between Broome and Delaware counties, where it turns south, on which general course it continues until near the Pennsylvania line, whence its course is southwesterly to Port Jervis. This portion of the river is the boundary line between New York and Pennsylvania. At Port Jervis the river passes from New York State, making a sharp turn to the southwest. The declivity of Delaware River is shown by the following elevations above tide water:

Elevations along Delaware River in New York State, showing declivity of the stream.

	Feet.
At Lackawaxen	600
At Deposit	984
At head waters	1,886

The principal tributary in New York State is Pepacton River, which rises in the eastern part of Delaware and Greene counties and flows southwest in a course generally parallel to the main stream. Neversink Creek, the next important tributary in the State, joins the main stream at the State line a mile south of Port Jervis. Neither of these streams has thus far developed any large amount of water power, although there are a number of places where good powers could be developed. The cutting off of the forests of the Delaware drainage area has undoubtedly greatly injured the tributary streams for mill purposes.

The following are the more important drainage areas on the Delaware and its tributaries in New York State:

Drainage areas on Delaware River and tributaries in New York State.

	Square miles.
Total area in New York State	2,580
Main stream below mouth of Neversink River	3,600
Main stream below Port Jervis	3,252
Main stream below junction of East and West branches	1,604
West Branch at mouth	685
West Branch at Deposit, below Oquaga Creek	519
Pepacton River at mouth	919
Above mouth of Beaverkill	520
Beaverkill Creek	322
Oquaga Creek	82
Little Delaware Creek	53
Neversink River at mouth	346

By way of concluding the general discussion of the Allegheny, Susquehanna, and Delaware river systems in the State of New York, it may be remarked that these have all been extensively used, either for floating logs or for propelling sawmills, or for both. The clearing up of the drainage areas has, however, long since reduced the lumbering business to nothing. These streams are, therefore, much less extensively utilized than formerly. At present, aside from one or two points, their use is chiefly for propelling small sawmills and gristmills and for other moderate-sized industries. With one or two exceptions, there are no large power developments throughout the whole region.

STREAMS OF LONG ISLAND.

Long Island is chiefly a sandy plain, about 120 miles in length, with a total area of 1,682 square miles. A considerable portion is below an elevation of 100 feet above tide water, although in places it rises to elevations of 300 feet and more. The streams are all small and only a few miles in length, running down from the high land of the middle section to the Atlantic Ocean on the south and to Long Island Sound on the north. As regards water power, the water resources of Long Island have little significance, although there are many places where small powers are utilized for gristmills and other similar uses. The chief value of the inland water of Long Island is for the water supply of the city of Brooklyn.

East River, which connects Long Island Sound with New York Bay, may also be referred to for convenience as a Long Island water resource. The great value of the stream to the commerce of New York is so obvious as to hardly require mention.

The foregoing description of the river systems of New York has

been made as brief as possible, because very complete descriptions have been given in the several monographs relating to New York State which appear in the report on the Water Power of the United States, Tenth Census, 1880. In these reports may be found full details of the several river valleys, with statements as to agricultural production, population, geology, climatology, and many other subjects not touched on here.

AVAILABLE WATER SUPPLY.

RUN-OFF OF NIAGARA RIVER.

The great developments of the Niagara Falls Power Company, authorized by the laws of 1886, have been in part completed, while at the same time the original Niagara Falls power development, now owned by the Niagara Falls Power and Manufacturing Company, has increased greatly in capacity. The laws of 1886, and amendments thereto, have also authorized the taking from Niagara River of large quantities of water for the purpose of creating a water power near the city of Lockport. A ship canal is projected connecting Lakes Erie and Ontario, and the Canadian Government has made a concession for extensive power developments on the Canadian side of the river. Hence it is evident that the future demands for water to be taken from Niagara River and delivered either into the lower river below the Falls or into Lake Ontario independent of the river are very large, and the interest which the people of the State of New York have in the run-off of Niagara River becomes exceedingly important.

The most recent determination of the area of the basin drained by the Great Lakes and of the water surfaces of the lakes themselves is that given in the report of the United States Deep Waterways Commission, from which the following general summary is taken:

Water surface and watershed areas of the basin drained by the Great Lakes.

Lake.	Area of water surface.	Area of watershed.	Total area of basin.
	Square miles.	*Square miles.*	*Square miles.*
Superior	31,800	48,600	80,400
Michigan	22,400	45,700	68,100
Huron	23,200	52,100	75,300
St. Clair	495	6,320	6,815
Erie	10,000	24,480	34,480
Total	87,895	177,200	265,095

That portion of the drainage area of Lake Erie lying within the State of New York is given as 2,210 square miles. The area of islands in Niagara River is given as 29 square miles. That portion of the watershed of Niagara River lying within the State of New York has an area of 789 square miles. The area of the river itself, from its head at Lake Erie to the Falls, is 21 square miles.[1]

The accompanying table gives the precipitation within and in the vicinity of the drainage area of the Great Lakes for the years from 1892 to 1895, inclusive. In this table a few only of the many precipitation records which are now available have been used. The records there appearing are, it is believed, sufficient to show the mean precipitation of the basin of the Great Lakes for the years indicated. In this and subsequent tables the water year[2] is considered as beginning with the month of December of the preceding year. Thus the water year of 1879 extends from December, 1878, to November, 1879, inclusive. The months from December to May constitute what may be termed the storage period. During this time vegetation is inert, the temperature low, with consequent light evaporation. Usually from 70 to 80 per cent of the precipitation of this period runs off in the streams.

June to August, inclusive, is the growing period. Then the temperature is at its highest for the year and vegetation is active. For this period only about 20 per cent of the rainfall appears in the streams, and some of that is usually the stored ground water of the preceding period.

September to November, inclusive, is the replenishing period. The temperature is again relatively low, vegetation inert, and the rainfall goes to replenish the stock of ground water, depleted during the growing period, or, after the ground again becomes full, appears as direct run-off in the streams. In the table the monthly precipitation has been omitted, as it can readily be found in the annual reports of the United States Weather Bureau, and the data have been condensed to show the total quantities for the storage, growing, and replenishing periods, together with the total annual amounts.

[1] Report of the United States Deep Waterways Commission, by the commissioners, James B. Angell, John E. Russell, Lyman E. Cooley. Accompanied by the report on technical work and the several topical reports and drawings pertaining thereto. Printed as House Document No. 192, Fifty-fifth Congress, second session, Washington, 1897, pp. 146, 147.

For the drainage area of the Great Lakes in detail reference may be made to an excellent map of the basin of the Great Lakes and of St. Lawrence and Hudson rivers in relation to the surrounding drainage systems accompanying the report of the Deep Waterways Commission.

[2] Report of the State Engineer and Surveyor of New York, 1895, p. 99.

Precipitation, in inches, within and in the vicinity of the drainage area of the Great Lakes, 1892 to 1895, inclusive.

Locality and year.	December to May.	June to August.	September to November.	Annual.
Pokegama Falls, Minn.:				
1892	11.76	6.99	2.86	21.61
1893	9.64	13.06	2.84	25.54
1894	14.72	8.04	9.01	31.77
1895	9.14	12.49	5.70	27.33
Mean				*26.56*
Duluth, Minn.:				
1892	17.96	11.78	2.39	32.13
1893	11.08	6.86	3.64	21.58
1894	19.44	8.80	8.51	31.75
1895	6.44	9.32	7.70	23.46
Mean				*27.23*
Minneapolis, Minn.:				
1892	13.78	23.32	2.33	39.43
1893	12.80	9.79	5.68	28.27
1894	15.66	1.73	6.46	23.85
1895	7.72	9.96	5.01	22.69
Mean				*28.56*
Green Bay, Wis.:				
1892	14.95	12.47	7.95	35.37
1893	14.85	8.12	7.15	30.12
1894	19.65	8.52	10.46	38.63
1895	10.06	7.52	3.14	20.72
Mean				*31.21*
Madison, Wis.:				
1892	18.89	13.34	4.89	37.12
1893	13.37	12.75	5.82	31.94
1894	10.96	6.23	7.61	24.80
1895	5.54	3.88	2.57	11.99
Mean				*26.46*
Milwaukee, Wis.:				
1892	18.17	11.00	5.71	34.88
1893	15.69	10.14	6.06	31.89
1894	15.94	4.81	8.79	29.54
1895	10.34	7.45	5.33	23.12
Mean				*29.86*

Precipitation, in inches, within and in the vicinity of the drainage area of the Great Lakes, 1892 to 1895, inclusive—Continued.

Locality and year.	December to May.	June to August.	September to November.	Annual.
Chicago, Ill.:				
1892	16.08	14.66	5.56	36.25
1893	13.93	6.85	6.18	26.96
1894	14.48	3.16	10.30	27.94
1895	9.58	10.70	7.00	27.28
Mean				*26.61*
Logansport, Ind.:				
1892	27.26	10.91	6.97	45.14
1893	24.45	4.52	8.92	37.89
1894	21.11	4.58	7.82	33.51
1895	9.08	6.40	8.56	24.04
Mean				*35.15*
Ann Arbor, Mich.:				
1892	14.52	8.18	7.70	30.38
1893	20.54	7.18	10.33	38.05
1894	16.63	2.76	7.21	26.60
1895	8.92	5.40	4.70	19.02
Mean				*28.51*
Grand Haven, Mich.:				
1892	16.57	8.93	4.97	30.47
1893	19.02	6.79	8.68	34.49
1894	19.84	4.07	11.08	34.99
1895	10.89	4.88	6.17	21.94
Mean				*30.47*
Marquette, Mich.:				
1892	16.03	3.53	8.89	28.45
1893	14.81	9.16	7.41	31.38
1894	24.65	5.25	9.31	39.21
1895	16.35	7.04	8.89	32.28
Mean				*32.83*
St. Ignace, Mich.:				
1892	12.39	10.30	6.43	29.12
1893	15.61	7.94	8.31	31.86
1894	17.80	6.83	9.80	34.43
1895	11.66	4.59	8.98	25.23
Mean				*30.16*

Precipitation, in inches, within and in the vicinity of the drainage area of the Great Lakes, 1892 to 1895, inclusive—Continued.

Locality and year.	December to May.	June to August.	September to November.	Annual.
Traverse City, Mich.:				
1892	17.65	10.87	8.61	37.13
1893	17.88	7.07	11.41	36.36
1894	20.62	5.61	9.72	35.95
1895	16.69	4.53	7.85	29.07
Mean				*34.63*
Cleveland, Ohio:				
1892	19.84	11.91	5.90	37.65
1893	19.09	5.46	7.45	32.00
1894	15.28	5.55	7.77	28.60
1895	9.29	7.59	7.91	24.79
Mean				*30.76*
Toledo, Ohio:				
1892	17.77	12.76	6.47	37.00
1893	10.17	4.81	6.92	21.90
1894	14.93	2.78	5.23	22.94
1895	9.23	6.24	7.11	22.58
Mean				*26.10*
Buffalo, N. Y.:				
1892	22.62	16.93	8.32	47.87
1893	20.65	8.00	7.87	36.52
1894	22.47	5.82	12.50	40.79
1895	14.17	6.23	8.85	29.25
Mean				*38.61*
Rochester, N. Y.:				
1892	17.75	13.41	5.94	37.10
1893	18.05	9.36	6.02	33.43
1894	21.26	7.05	7.14	35.45
1895	16.16	6.84	7.15	30.15
Mean				*34.03*
Oswego, N. Y.:				
1892	15.22	15.33	6.82	37.37
1893	14.63	9.83	8.01	32.47
1894	19.55	6.46	11.13	37.14
1895	15.06	6.25	9.08	30.39
Mean				*34.34*

Precipitation, in inches, within and in the vicinity of the drainage area of the Great Lakes, 1892 to 1895, inclusive—Continued.

Locality and year.	December to May.	June to August.	September to November.	Annual.
Winnipeg, Manitoba:				
1892	6.65	8.70	3.96	19.31
1893	8.25	10.81	4.35	23.41
1894	8.55	3.80	5.84	18.19
1895	8.18	6.62	2.42	17.22
Mean				*19.53*
Port Arthur, Ontario:				
1892	8.84	7.35	5.31	21.50
1893	8.48	7.39	6.50	22.37
1894	8.20	5.57	8.30	22.07
1895	8.76	7.86	6.05	22.67
Mean				*22.15*
Toronto, Ontario:				
1892	12.21	12.29	6.65	31.15
1893	18.64	9.85	7.86	36.35
1894	19.90	3.07	8.44	31.41
1895	11.93	6.24	7.76	25.93
Mean				*31.21*

These precipitation data are of special interest because the year 1895 was the culmination of a period of exceedingly low water. They show that for a period of four years the precipitation of this basin was low, and in consequence the run-off of the tributary streams must have been exceedingly small. As illustrating this proposition, we may first refer to the run-off of the Upper Mississippi,[1] where there is a reservoir system controlling a drainage area of 3,265 square miles, first operated about 1885. The rainfall of the area tributary to these reservoirs, as indicated by records kept at Leech Lake, Lake Winibigoshish, and Pokegama Falls from 1885 until the present time is, as an average, from 24 to 26 inches per year. The highest recorded yearly precipitation is 31.87 inches, at Pokegama Falls in 1894. The rainfall of the area tributary to the Upper Mississippi reservoirs is found to be quite similar to that of the region tributary to Lake Superior. Hence the run-off of this reservoir system may be considered as representing the run-off of the drainage area of Lake Superior and the northern portion of Lakes Michigan and Huron.

[1] Annual Report of Chief of Engineers U. S. Army for 1896, Part III, p. 1843; also for 1897, Part III, p. 2169.

The following gives the discharge from these reservoirs for the years 1892 to 1895, inclusive, corresponding with the years of precipitation shown in the table on pages 50 to 53:

Mean rainfall, run-off, and proportion of run-off to rainfall of the area tributary to the Upper Mississippi reservoirs.

Water year.	Mean rainfall on watershed.	Run-off of watershed.	Proportion of run-off to rainfall.
	Inches.	*Inches.*	*Per cent.*
1892	21.33	4.43	20.8
1893	25.42	3.61	14.2
1894	26.63	3.62	13.6
1895	25.11	2.79	11.1
Total	98.49	14.45	
Mean	24.62	3.61	14.7

The table shows that during the years 1892 to 1895, inclusive, the mean run-off of the Upper Mississippi watershed was only 3.61 inches on the total watershed. These figures, however, are subject to correction because the state of the reservoirs at the beginning and ending of the four-year period is not given in the report of the United States engineers, from which these data are taken. This correction, however, can not be very large, because the reservoirs are so operated as to be emptied, generally speaking, each year. In considering the run-off of these Upper Mississippi reservoirs, due consideration should be given to the fact that the water area of the reservoirs is 585 square miles, or nearly 18 per cent of the whole. For Lakes Superior, Michigan, Huron, St. Clair, and Erie we have a total water surface of 87,895 square miles, with a total drainage area, including the surface of the lakes, of 265,095 square miles. The water surface of these several lakes is, therefore, about 33 per cent of the entire area of the basin, or nearly double the relative area of water surface and drainage area for the Upper Mississippi reservoirs. With other conditions the same, this fact would probably lead to a somewhat greater proportion of run-off from the Great Lakes.

By way of further illustrating the yield of streams in the vicinity of the Great Lakes drainage area, we may refer to the run-off of the Des Plaines River as given in the table on page 64. This stream has been measured by the Chicago drainage commission, with certain intermissions, as shown by the table, since January, 1886, the drainage area above the point of measurement being 633 square miles. The drainage area comprises a long and narrow, flat region extending from near Chicago to a few miles north of Milwaukee, the eastern line being for the entire distance nearly parallel to Lake Michigan and in

places only 2 or 3 miles distant therefrom. The area drained by the Des Plaines River is large enough to give a fair idea of the average yield of streams tributary to Lake Michigan in northern Illinois and Indiana, western Michigan, and southern and central Wisconsin. In 1893, with a mean rainfall on the drainage area of 39.96 inches, the total run-off was 10.14 inches, of which 8.61 inches occurred during the storage period from December to May, inclusive. In 1894, with a total rainfall of 27.94 inches, the total run-off was 7.70 inches, of which 7.54 inches occurred in the storage period. For the year 1895 the total rainfall was 27.28 inches. The run-off data of this year are unfortunately incomplete, but taking into account the sequence of the rainfall it is clear that the total run-off for that year did not exceed about 2.0 to 2.5 inches. The effect of the three dry years 1893, 1894, and 1895 in the Des Plaines drainage area is shown by the record of 1896, where, with a total rainfall of 39.58 inches, the total run-off was only 6.69 inches, of which 5.39 inches occurred in the storage period. These figures indicate that the ground water of the Des Plaines area must have been so low at the end of 1895 as to absorb a large portion of the heavier rainfall of 1896 before any great amount could appear as run-off.[1]

Rainfall, run-off, evaporation, and mean temperature of Muskingum River, as measured by the United States engineers, from 1888 to 1895, inclusive.

[In inches on the watershed.]

Month.	1888.				1889.				1890.			
	Rainfall.	Run-off.	Evaporation.	Temperature.	Rainfall.	Run-off.	Evaporation.	Temperature.	Rainfall.	Run-off.	Evaporation.	Temperature.
				°				°				°
December	1.94	0.18	.....	30.8	1.50	0.84	.....	31.5	3.01	1.48	.....	41.1
January	3.96	1.24	.....	23.5	3.63	1.89	.....	31.7	4.52	3.53	.....	37.0
February	1.91	1.12	.....	29.4	1.55	1.42	.....	24.0	5.84	3.73	.....	37.5
March	4.05	1.38	.....	32.5	1.71	0.71	.....	39.0	4.38	4.23	.....	32.0
April	1.75	0.80	.....	46.9	2.23	0.88	.....	47.9	3.41	2.00	.....	48.8
May	3.55	0.45	.....	58.4	2.90	0.28	.....	59.1	6.61	3.10	.....	56.9
	17.16	*5.17*	*11.99*	*36.9*	*13.52*	*6.02*	*7.50*	*38.9*	*27.77*	*18.07*	*9.70*	*42.2*
June	2.66	0.29	.....	68.4	4.79	0.47	.....	65.7	5.27	1.64	.....	70.7
July	5.81	0.81	.....	70.4	5.35	0.55	.....	71.7	3.06	0.51	.....	70.9
August	5.84	0.67	.....	68.8	1.98	0.22	.....	67.0	5.35	0.49	.....	66.6
	14.31	*1.77*	*12.54*	*69.2*	*12.12*	*1.24*	*10.88*	*68.1*	*13.68*	*2.64*	*11.04*	*69.4*
September	3.28	0.61	.....	58.0	4.17	0.14	.....	61.3	6.86	2.28	.....	60.6
October	3.25	0.77	.....	45.6	2.35	0.14	.....	46.5	6.20	2.01	.....	51.1
November	4.61	2.01	.....	41.1	3.72	0.68	.....	40.2	2.46	1.84	.....	42.0
	11.14	*3.39*	*7.75*	*48.2*	*10.24*	*0.96*	*9.28*	*49.3*	*15.52*	*6.13*	*9.39*	*51.2*
Year	42.61	10.33	32.28	47.8	35.88	8.22	27.66	48.8	56.97	26.84	30.13	51.3

[1] For details of the measurements of the Des Plaines River see data pertaining to rainfall and stream flow, by Thomas T. Johnston, Journal Western Soc. C. E., Vol. I (June, 1896).

Rainfall, run-off, evaporation, and mean temperature of Muskingum River, as measured by the United States engineers, from 1888 to 1895, inclusive—Cont'd.

Month.	1891.				1892.				1893.			
	Rainfall.	Run-off.	Evaporation.	Temperature.	Rainfall.	Run-off.	Evaporation.	Temperature.	Rainfall.	Run-off.	Evaporation.	Temperature.
				°				°				°
December	2.45	0.91	.....	29.3	2.62	1.03	.....	37.8	1.62	0.24	.....	28.1
January	2.52	2.40	.....	31.2	2.40	0.74	.....	22.8	3.01	0.37	.....	18.0
February	4.43	4.56	.....	34.8	2.76	2.40	.....	33.0	6.38	4.70	.....	28.3
March	3.19	2.52	.....	33.5	3.10	1.26	.....	32.7	2.31	2.55	.....	36.9
April	1.74	1.58	.....	49.8	2.24	1.38	.....	46.0	5.94	2.22	.....	49.6
May	2.39	0.45	.....	55.8	7.27	2.25	.....	57.9	5.78	4.05	.....	57.0
	16.72	*13.43*	*4.30*	*39.1*	*20.39*	*9.06*	*11.33*	*38.4*	*25.04*	*14.15*	*10.91*	*36.3*
June	7.56	0.91	.....	69.0	7.05	2.30	.....	71.6	3.08	0.78	.....	70.2
July	3.92	0.51	.....	67.6	5.44	0.75	.....	70.9	2.92	0.28	.....	73.6
August	2.08	0.35	.....	68.7	4.05	0.60	.....	70.0	2.31	0.16	.....	69.5
	13.56	*1.77*	*11.79*	*68.4*	*16.54*	*3.65*	*12.89*	*70.8*	*8.31*	*1.22*	*7.09*	*71.1*
September	1.08	0.17	.....	66.5	2.33	0.28	.....	62.2	1.56	0.14	.....	63.4
October	1.25	0.26	.....	49.7	0.80	0.20	.....	50.1	5.51	0.46	.....	52.4
November	4.75	0.94	.....	38.6	1.68	0.19	.....	37.8	1.94	0.25	.....	38.4
	7.08	*1.37*	*5.71*	*51.6*	*4.81*	*0.67*	*4.14*	*50.0*	*9.01*	*0.85*	*8.16*	*51.4*
Year	37.36	15.56	21.80	49.5	41.74	13.38	28.36	49.4	42.36	16.20	26.16	48.8

Month.	1894.				1895.				Mean.			
	Rainfall.	Run-off.	Evaporation.	Temperature.	Rainfall.	Run-off.	Evaporation.	Temperature.	Rainfall.	Run-off.	Evaporation.	Temperature.
				°				°				°
December	2.59	1.54	.....	31.7	3.01	0.36	.....	33.2	.....	.....	.....	.....
January	2.11	1.00	.....	33.2	3.99	1.67	.....	22.4	.....	.....	.....	.....
February	2.95	2.19	.....	27.6	0.89	0.12	.....	19.1	.....	.....	.....	.....
March	2.20	1.41	.....	43.9	1.87	1.20	.....	33.2	.....	.....	.....	.....
April	2.45	0.75	.....	49.8	1.76	0.59	.....	50.6	.....	.....	.....	.....
May	4.63	0.74	.....	58.3	1.52	0.10	.....	60.5	.....	.....	.....	.....
	16.93	*7.63*	*9.30*	*40.7*	*13.04*	*4.04*	*9.00*	*36.5*	*18.82*	*9.57*	*9.25*	*38.6*
June	2.12	0.42	.....	70.6	2.87	0.17	.....	71.6	.....	.....	.....	.....
July	1.77	0.13	.....	73.1	2.52	0.21	.....	69.6	.....	.....	.....	.....
August	0.67	0.11	.....	70.1	3.75	0.11	.....	71.7	.....	.....	.....	.....
	4.56	*0.66*	*3.90*	*71.3*	*9.14*	*0.49*	*8.65*	*71.0*	*11.53*	*1.68*	*9.85*	*69.9*
September	4.12	0.15	.....	67.2	2.39	0.13	.....	67.2	.....	.....	.....	.....
October	2.19	0.10	.....	53.3	1.38	0.08	.....	45.3	.....	.....	.....	.....
November	2.71	0.16	.....	36.8	3.89	0.16	.....	40.8	.....	.....	.....	.....
	9.02	*0.41*	*8.61*	*52.4*	*7.66*	*0.37*	*7.29*	*51.1*	*9.31*	*1.77*	*7.54*	*50.7*
Year	30.51	8.70	21.81	51.3	29.84	4.90	24.94	48.8	30.66	13.02	26.64	49.5

In the table is given the rainfall and run-off record for Muskingum River, in Ohio, as measured at Zanesville[1] for the years 1888 to 1895, inclusive, the area of the watershed above the point of measurement being 5,828 square miles. The head waters of the stream are not far from Lake Erie and on the dividing line between the hill country of the east and the prairie country of the Mississippi Valley. Hence this stream represents conditions applicable to the run-off of the Ohio streams tributary to Lake Erie. The rainfall record as used in this table is the mean of the records kept at Akron, Canton, Newcomerstown, and Wooster, and may be considered to represent fairly well the mean precipitation of the Muskingum drainage area. For the year 1892 the total rainfall was 41.74 inches and the total run-off 13.38 inches, of which 9.06 occurred in the storage period. In 1893 the total rainfall was 42.36 inches, with a total run-off of 16.20 inches, the run-off of the storage period being 14.13 inches. In 1894 the rainfall dropped to a total of 30.51 inches and the run-off to a total of 8.70 inches, of which 7.63 inches occurred in the storage period. In 1895 the total rainfall was 29.84 inches and the total run-off 4.90 inches, of which 4.04 inches occurred during the storage period.

Genesee River, while not tributary to the Great Lakes above Niagara River, may still be cited as showing that at times the run-off of streams tributary to the Great Lakes is quite low. Referring to the table on page 70, giving the rainfall and run-off of Oatka Creek, a tributary of the Genesee, we learn that in the water year 1891, with a rainfall of 38.12 inches, the run-off was 14.05 inches. In 1892, with a rainfall of 41.69 inches, the run-off was 15.42 inches.

Taking the record of Genesee River proper, as given in the table on page 58, we learn that for the water year 1894, with a mean precipitation above the point of measurement of 47.79 inches, the run-off was 19.38 inches, of which 15.73 inches occurred in the storage period. In 1895 the rainfall dropped to 31 inches and the total run-off to 6.67 inches. In 1880 Hemlock Lake, a tributary of Genesee River, with a drainage area of 43 square miles and a total rainfall of 21.99 inches, gave a run-off of only about 3.4 inches.

[1] Survey of the Miami and Erie Canal, the Ohio Canal, etc. Report of Capt. Hiram M. Chittenden, Corps of Engineers, U. S. Army, January 20, 1896, printed as House Document No. 278, Fifty-fourth Congress, first session, p. 42.

Rainfall, run-off, evaporation, and mean temperature of Genesee River from December, 1893, to November, 1896, inclusive.

[In inches on the watershed.]

Month.	1894.				1895.				1896.			
	Rainfall.	Run-off.	Evaporation.	Mean temperature	Rainfall.	Run-off.	Evaporation.	Mean temperature.	Rainfall.	Run-off.	Evaporation.	Mean temperature.
				°				°				°
December	3.39	2.34	.....	26.8	2.47	0.61	.....	29.0	3.80	1.32	.....	30.1
January	3.91	1.40	.....	28.4	3.26	0.66	.....	1.91	2.29	0.47	.....	22.4
February	2.93	0.86	.....	20.1	1.22	0.22	.....	14.5	3.56	0.91	.....	23.9
March	1.62	3.31	.....	37.9	1.72	1.94	.....	28.0	4.00	3.00	.....	22.7
April	7.22	3.39	.....	42.1	2.10	2.01	.....	44 2	1.62	3.38	.....	47.7
May	8.64	4.43	.....	54.5	2.43	0.19	.....	57.8	2.57	0.17	.....	60.7
	27.71	*15.73*	*11.98*	*35.0*	*13.30*	*5.63*	*7.57*	*32.1*	*17.84*	*9.25*	*8.59*	*34.4*
June	2.51	1.10	.....	64.6	4.57	0.13	.....	67.5	3.52	0.39	.....	62.1
July	3.70	0.14	.....	67.9	2.57	0.11	.....	64.1	4.90	0.24	.....	67.3
August	1.74	0.22	.....	63.4	3.99	0.12	.....	66.5	1.86	0.20	.....	65.0
	7.95	*1.46*	*6.49*	*65.3*	*11.13*	*0.36*	*10.77*	*66.0*	*10.28*	*0.83*	*9.45*	*64.8*
September	6.97	0.93	.....	61.6	1.96	0.10	.....	61.7	5.22	0.16	.....	57.5
October	3.50	0.44	.....	49.5	1.30	0.11	.....	41.8	4.08	1.74	.....	43.6
November	1.66	0.82	.....	32.1	3.41	0.47	.....	38.0	3.26	0.82	.....	41.6
	13.13	*2.19*	*9.94*	*47.7*	*6.67*	*0.68*	*5.99*	*47.2*	*13.56*	*2.72*	*9.84*	*47.6*
Year	47.79	19.38	28.41	45.7	31.00	6.67	24.33	44.3	40.68	12.80	27.88	45.3

These figures are cited to show that in years of low rainfall the run-off of streams tributary to the Great Lakes is very low, and as a consequence the run-off of Niagara River will probably be affected thereby. At present the data are insufficient for showing what the run-off of Niagara River really is.

The most elaborate measurements thus far made are those of the Lake Survey in 1867 and 1868, which are, however, extremely unsatisfactory. According to these measurements the mean discharge, rainfall, and evaporation from the Great Lakes for the year 1868, in cubic feet per second, were as follows:[1]

Mean discharge, rainfall, and evaporation from the Great Lakes for the year 1868, in cubic feet per second.

Lakes.	Mean discharge.	Total rainfall on basin.	Evaporation from surface.
Superior	86,000	171,430	27,690
Huron and Michigan	225,000	251,450	59,890
Erie	265,000	100,540	14,310
Total	.....	523,220	101,890

[1] These figures are derived from Mr. Cooley's Lakes and Gulf Waterways, as corrected and given in the Journal of the Assoc. of Eng. Soc., Vol. VIII (March, 1889), p. 132.

According to the Deep Waterways Commission's tabulations of available records of heights of the Great Lakes, it appears that the water levels fluctuate through a series of years to the extent of about 4.5 feet. For the present discussion we are chiefly concerned with the fluctuations of Lake Erie, which control the discharge of Niagara River. By examination of the records of mean monthly elevation of Lake Erie at Buffalo from 1887 to 1897, as kept by the United States engineer's office at Buffalo, it appears that the highest mean monthly elevation during these years was for June, 1887, when the mean lake surface was +0.92. The lowest mean monthly elevation for the period was for March, 1896, when the mean for the month was −2.36. The range in the mean monthly elevations for this period was 3.28 feet.

Mean monthly elevation of Lake Erie at Buffalo.

[In feet with reference to datum.]

Month.	1887.	1888.	1889.	1890.	1891.	1892.	1893.	1894.	1895.	1896.	1897.
December	.....	−0.26	−0.31	−0.71	−0.31	−1.35	−1.01	−0.92	−1.23	−2.08	−1.82
January	.....	−0.48	−0.49	−0.13	−0.57	−1.44	−1.78	−0.92	−1.36	−1.93	−1.47
February	.....	−1.09	−0.71	−0.31	−0.69	−2.13	−1.83	−1.30	−2.05	−2.00	−1.90
March	+0.60	−1.02	−1.10	−0.07	−0.55	−1.93	−1.52	−1.19	−2.13	−2.36	−1.39
April	+0.56	−0.36	−0.72	+0.18	−0.43	−1.09	−0.86	−1.00	−1.92	−1.83	−0.87
May	+0.78	−0.21	−0.56	+0.54	−0.65	−0.65	−0.14	−0.50	−1.57	−1.38	−0.45
	+0.64	*−0.57*	*−0.65*	*−0.08*	*−0.53*	*−1.43*	*−1.19*	*−0.97*	*−1.71*	*−1.93*	*−1.33*
June	+0.92	−0.04	−0.09	+0.87	−0.67	+0.16	+0.21	−0.11	−1.47	−1.37	−0.46
July	+0.76	+0.18	−0.05	+0.59	−0.49	+0.37	+0.08	−0.24	−1.49	−1.19	−0.48
August	+0.36	+0.07	−0.14	+0.12	−0.78	+0.00	−0.51	−0.71	−1.63	−0.96	−0.96
	+0.68	*+0.07*	*−0.09*	*+0.53*	*−0.65*	*+0.18*	*−0.07*	*−0.36*	*−1.53*	*−1.18*	*−0.63*
September	+0.05	−0.27	−0.52	−0.23	−0.95	−0.27	−0.76	−0.08	−1.61	−1.38	−1.40
October	+0.11	−0.46	−1.03	−0.25	−1.32	−0.60	−0.87	−0.88	−1.85	−1.64	−1.36
November	−0.44	−0.61	−1.03	−0.05	−1.38	−0.98	−0.88	−1.06	−2.34	−1.61	−1.24
	−0.09	*−0.45*	*−0.86*	*−0.17*	*−1.22*	*−0.62*	*−0.84*	*−0.67*	*−1.93*	*−1.54*	*−1.33*
Year	[a]+0.41	−0.38	−0.56	+0.05	−0.73	−0.83	−0.82	−0.74	−1.72	−1.64	−1.15

[a] Mean of nine months.

Temporarily much greater fluctuations have been experienced, due largely to wind action, to which Lake Erie, on account of its shallowness, and the fact that its general direction is favorable for the sweep of the prevailing winds, is peculiarly subject. In regard to the measurements of the Lake Survey, it may be remarked that they indicate large variations in discharge from all of the lakes, from the effects of winds and other disturbing causes, but give little clew to the quantities at either of the extremes of high or low water. According to Lyman E. Cooley the extreme low-water discharge is probably 20 to 30 per cent less than the Lake Survey figures, and extreme high water 20 to 30 per cent more.

Measurements of the amount of water flowing in Niagara River were begun in December, 1891, at a time when the water in Lake Erie was very low and the conditions were considered especially favorable for

minimum discharge. The results are given in the Annual Report of the Chief of Engineers, United States Army, for 1893, Part VI, pp. 4364–4371. The point selected was about 1,000 feet below the International Bridge at Black Rock, near the foot of Squaw Island, at which point the river is free from eddies. Niagara River, on leaving Lake Erie, has a nearly straight channel about 2,000 feet wide for the first 2 miles. The fall in this section is from 4 to 5 feet, and the velocity ranges from 7 miles per hour at the upper end to about 5 miles at the lower end. The point was chosen, after careful consideration, as the point in that vicinity least subject to disturbance. In taking the cross sections, the width, which varies slightly with different stages of the river, was actually determined for gage readings 1 foot apart, and for extreme points the width was determined by interpolating values derived from the known slope of the river banks. A local gage was established at the draw pier of the International Bridge by setting gage boards on each side of the pier, with the zeros of the gages on the same level. The local gage was read at the beginning and close of all velocity observations, and the gage at Buffalo was read at 7 a. m. and 1 and 7 p. m. The zero of this latter gage is at the mean level of Lake Erie, or 572.23 feet above mean tide at New York, in the Erie Canal levels, or as used by the Government engineers, 572.96 feet. During the velocity observations in December, 1891, Lake Erie was about 1.5 feet below its mean level, and is stated not to have been seriously affected by strong winds. Still the daily record shows that there must have been some wind action. The current velocities were obtained after the methods used by the Mississippi River Commission and described in their reports, all velocity observations being taken with a current meter, with electrical appliances for recording the number of revolutions. The following are some of the results obtained:[1]

Mean heights and discharge of Niagara River.

Date.	Mean height on local gage.	Mean height on Buffalo gage.	Discharge per second.
1891.	*Feet.*	*Feet.*	*Cu. feet.*
December 24	0.05	—2.95	164,648
December 14	0.65	—1.85	191,822
December 21	0.735	—1.75	193,522
December 20	0.835	—1.75	201,433
December 22	1.125	—1.45	208,597
December 10	1.33	—0.50	218,353
1892.			
May 19	1.562	—0.80	213,180
May 7	1.750	—0.85	218,988
May 24	2.292	+0.15	236,762

[1] Annual Report of Chief of Engineers, United States Army, 1893, Part VI, p. 4367.

The table shows (1) a variation in lake elevation, as indicated in the Buffalo gage, from —2.95 on December 24, 1891, to +0.15 on May 24, 1892, a range of 3.10 feet; (2) a variation in discharge of 72,114 cubic feet per second. There are some discrepancies in the results which it is not necessary to discuss at length; but in the absence of more satisfactory data we may assume, in view of the foregoing evidence as to the small run-off of streams tributary to and in the vicinity of the Great Lakes, that the figures obtained in the fall of 1891 and spring of 1892 are probably more nearly correct than the larger figures of the Lake Survey. By plotting the observed discharges a mean discharge curve has been obtained, from which the discharge of the river at points within the range of the observation can be taken off, when one has the tabulated heights of the Buffalo gage before him. At present these measurements are, on the whole, not considered sufficiently exact to justify the labor of preparing a tabulation of this character.[1]

Referring to the table on page 58, it is learned that the rainfall in that portion of the basin of the Great Lakes tributary to Niagara River was, for 1868, 523,220 cubic feet per second, and the evaporation from the water surface of the lakes tributary to Niagara River was 101,890 cubic feet per second. Hence the evaporation from the lake surfaces was nearly 20 per cent of the rainfall on the whole basin. Assuming for the moment the truth of these figures, we have 80 per cent of the total rainfall from which the land evaporation must be deducted before anything can run off. Again assuming the land evaporation at 1.70 feet, there results a loss from this source alone of 298,000 cubic feet per second; adding to this the evaporation loss from the water surfaces gives a total evaporation loss of 399,890 cubic feet per second. The run-off is the difference between rainfall and total evaporation losses. If, therefore, the land evaporation was 1.7 feet for the year 1868, the run-off would have been in reality only 123,330 cubic feet per second instead of 265,000 cubic feet per second, as

[1] There have been a number of independent measurements of volume of the Niagara, and though the results differ widely, they probably do not differ more than the actual volume of the river at various stages of Lake Erie.

Lyell (1841 ?) quotes Ruggles as authority for a volume of 250,000 cubic feet per second.

E. R. Blackwell, computed by Allen (Am. Jour Sci., 1841), obtains 374,000 cubic feet per second. His work was afterwards recomputed by D. F. Henry, who obtained 244,797 cubic feet per second.

In the annual report of the Chief of Engineers, United States Army, for 1867-68, D. F. Henry gives as a result of observations in August and September, 1867, 242,494 cubic feet per second. A year later he recomputed from the same data, and obtained 240,192 cubic feet per second. He also made a new measurement by a different method (see Report for 1868-69) from which he obtained two results, 304,307 and 258,586 cubic feet per second.

W. F. Reynolds (annual report of the Chief of Engineers, United States Army, 1870?), gives the result of observations from June to September, 1869, 212,860 cubic feet per second.

In the annual report of the Chief of Engineers, United States Army, for 1871, there is mention of a result, without date of measurement, 245,296 cubic feet per second.

In the annual report of the Chief of Engineers, United States Army, for 1891-92, Quintus, as a result of gaging, gives the volume, reduced to mean stage, as 232,800 cubic feet per second.

Sir Casimir S. Gzowski, from continuous observations at the International Bridge, 1870-1873, gives an average discharge for that period of 246,000 cubic feet per second.

determined by the Lake Survey. These figures, while not conclusive, are suggestive, so much so, indeed, that taking into account all the conditions it seems clear that in a series of years of minimum rainfall the run-off of the Great Lakes, tributary to Niagara River, may be as low as from 6 to 9 inches a year on the watershed. At the former figure the mean discharge would be about 177,700 cubic feet per second.[1]

As an additional source of loss from the Great Lakes the proposed ultimate diversion of 10,000 cubic feet per second through the Chicago drainage canal to the head waters of Illinois River may be referred to. Thus far the discussion of such loss has been mainly conducted on the supposition that the mean discharge of the Great Lakes at Niagara was about 265,000 cubic feet per second. If this were true the ultimate injurious effect of such diversion could only appear during a series of extremely dry years. The author can not but think that this whole question of the run-off of Niagara River has become fogged by a discussion based thus far purely on averages. What we really want to know is the run-off of a cycle of dry years. With such data we can compute the effect of a given diversion more satisfactorily than when dealing with means.

With a cycle of rainfall years, either high or at about the average, it is probable that very little effect from such diversion will be observed, the consensus of opinion at the present time apparently being that it will not exceed about 0.3 to 0.4 foot in depth over the areas affected. Owing to the balancing of conditions due to the immense pondage of the Great Lakes, and which requires years in order to complete a cycle, it is uncertain whether the abstraction of 10,000 cubic feet per second at Chicago would be especially detrimental at Niagara Falls, although in years of extreme low flow it is probable that it would be easily apparent. If, however, the minimum flow of Niagara River is really as low as 150,000 to 180,000 cubic feet per second, it is clear that the loss of 10,000 cubic feet per second will be a matter worth taking into account.

In the discussion of the effect of diverting 10,000 cubic feet per second at Chicago on the levels of the Great Lakes, by Lyman E. Cooley, which appears in the proceedings of the annual convention of the International Deep Waterways Association, held at Cleveland in September, 1895, it is stated that assuming the correctness of the

[1] By way of illustrating further the probable inaccuracy of the Lake Survey figures, it may be pointed out that if the determination of evaporation from the water surfaces at 101,890 cubic feet per second and run-off at 265,000 cubic feet per second for the year 1868 is correct, the total outgo from these two sources was 368,890 cubic feet per second, leaving the land evaporation for that year at 156,330 cubic feet per second, or at 0.9 foot over the watershed.

By studying the evaporation of the Upper Mississippi reservoirs, the Des Plaines and Muskingum rivers, and other streams herein referred to, it will readily be seen that it is exceedingly improbable that a land evaporation as low as 0.9 foot ever occurred over the whole watershed of the Great Lakes.

figures derived from the Lake Survey placing the mean discharge of St. Clair River at 225,000 cubic feet per second, the abstraction of 10,000 cubic feet per second would diminish the mean outflow in St. Clair River by nearly 4.5 per cent and in Niagara River by about 3.75 per cent. Mr. Cooley says that, reasoning on lines obvious to those unacquainted with hydraulic principles, it is apparent that the ruling depth in the rivers at mean level can not be lessened by an amount greater than the percentages just stated; but if we consider the question as an hydraulic proposition, taking into account the relation of mean radius to area and perimeter, it is apparent that the effect on lake levels would be only a fraction of that indicated by the reduction in volume.

The literature of the discharge of Niagara River and of the probable effect on the lake levels of abstracting 10,000 cubic feet per second at Chicago has now grown so extensive as to preclude further discussion of the question here. Those wishing to pursue the subject further may consult the references given in the footnote. Concluding the subject, it may be stated that the studies of the Lake Survey indicate a mean discharge of Niagara River of about 265,000 cubic feet per second, with a range above and below the mean of from 20 to 30 per cent. The only measurements since made were those of December to May, 1891–92, which indicate a minimum discharge as low as or even lower than 141,000 cubic feet per second, this latter figure agreeing fairly well with theoretical considerations derived from present knowledge of the actual minimum run-offs of contiguous drainage areas.[1]

[1] For literature of discharge of Great Lakes and allied questions see (1) Repts. Chief of Engnrs. 1868, 1869, 1870, and 1882; (2) Repts. Chief of Engnrs., 1893; (3) Eng. News, Vol. XXIX (March 2, 1893); (4) The Lakes and Gulf Waterways, by L. E. Cooley; (5) The level of the Lakes as affected by the proposed Lakes and Gulf waterway, a discussion before the Western Society of Engineers, in Jour. of the Assn. of Eng. Socs., Vol. VIII (Mch., 1889); (6) An enlarged waterway between the Great Lakes and the Atlantic seaboard, by E. L. Corthell, with discussion, in Jour. of the Assn. of Eng. Socs., Vols. X and XI (April, June, and December, 1891, and July, 1892); (7) Lake level effects on account of the sanitary canal at Chicago, by L. E. Cooley, in Proc. Internat. Deep Waterways Con., at Cleveland, Sept., 1895; (8) A technical brief, by Thomas T. Johnston, covered by the preceding reference; (9) Papers by William Pierson Judson, on an Enlarged waterway between the Great Lakes and the Atlantic seaboard, pamphlets, 1890 and 1893.

Rainfall and run-off of Des Plaines River, as determined by the Chicago drainage commission, from 1886 to 1897.

[Inches on watershed.]

Months.	1886.		1887.		1888.		1889.		1890.		1891.	
	Rainfall.	Run-off.	Rainfall.	Run-off.	Rainfall.	Run-off.	Rainfall.	Run-off.	Rainfall.	Run-off.	Rainfall.	Run-off.
December	.....	.....	1.76	0.00	3.67	.....	1.94	0.00	1.90	.....	.....	.....
January	.....	.....	3.13	0.89	1.56	1.37	1.64	0.29	.....	.....	.....	.....
February	.....	.....	5.10	5.59	1.51	2.50	1.31	0.01	.....	.....	.....	.....
March	.....	.....	0.89	2.64	2.99	4.84	1.43	0.43	.....	.....	.....	.....
April	.....	.....	0.46	0.52	.....	.....	2.35	1.13	.....	.....	.....	.....
May	.....	.....	1.38	0.13	.....	.....	5.38	0.39	.....	.....	.....	.....
			12.72	*9.77*	.....	.....	*14.05*	*2.25*	.....	.....	.....	.....
June	0.94	0.16	1.63	0.02	.....	.....	2.93	1.26	.....	.....	.....	.....
July	1.53	0.14	1.05	0.33	.....	.....	9.56	1.09	2.57	.....	.....	.....
August	3.38	0.01	3.35	0.18	.....	.....	0.39	0.45	2.58	0.02	.....	.....
	5.85	*0.31*	*6.03*	*0.53*	.....	.....	*12.88*	*2.80*	.....	.....	.....	.....
September	6.93	0.03	4.03	0.22	0.98	.....	2.75	0.00	1.39	0.01	.....	.....
October	1.42	0.01	2.03	0.63	2.95	0.00	1.82	0.00	4.20	0.02	.....	.....
November	1.66	0.00	2.41	.....	2.89	0.00	3.49	0.01	1.59	0.04	.....	.....
	10.01	*0.04*	*8.47*	.....	*6.82*	.....	*8.06*	*0.01*	*7.18*	*0.07*	.....	.....
Year	.....	.....	27.22	.....	.....	.....	34.99	5.06	.....	.....	.....	.....

Months.	1892.		1893.		1894.		1895.		1896.		1897.	
	Rainfall.	Run-off.	Rainfall.	Run-off.	Rainfall.	Run-off.	Rainfall.	Run-off.	Rain. fall.	Run-off.	Rainfall.	Run-off.
December	.....	.....	1.63	0.04	2.14	0.27	1.66	.....	6.76	1.80	0.16	0.19
January	.....	.....	2.08	0.01	1.55	0.50	2.15	.....	1.12	0.26	4.53	.....
February	.....	.....	2.44	0.31	2.13	1.06	1.60	0.21	3.48	1.08	2.22	1.39
March	.....	.....	1.69	5.15	2.66	3.05	1.32	0.71	1.26	1.11	3.56	4.61
April	.....	.....	4.16	1.79	2.65	0.76	0.86	0.29	2.79	0.77	2.23	1.88
May	6.77	4.24	1.93	1.31	3.35	1.90	1.99	0.11	4.16	0.39	0.84	0.60
			13.93	*8.61*	*14.48*	*7.54*	*9.58*	.....	*19.57*	*5.39*	*13.54*	.....
June	10.58	6.04	3.59	1.37	1.96	0.08	1.79	0.00	2.82	0.09	.....	.....
July	2.23	0.79	3.08	0.14	0.60	0.01	2.42	0.00	3.61	0.02	.....	.....
August	1.85	0.03	0.18	0.00	0.60	0.00	6.49	0.01	3.52	0.06	.....	.....
	14.66	*6.86*	*6.85*	*1.51*	*3.16*	*0.09*	*10.70*	*0.01*	*9.95*	*0.17*	.....	.....
September	1.34	0.02	1.98	0.00	8.28	0.06	0.89	0.06	6.54	0.32	.....	.....
October	1.54	0.00	1.75	0.02	0.84	0.00	0.51	0.00	1.36	0.33	.....	.....
November	2.68	0.02	2.45	0.00	1.18	0.01	5.60	0.00	2.16	0.48	.....	.....
	5.56	*0.04*	*6.18*	*0.02*	*10.30*	*0.07*	*7.00*	*0.06*	*10.06*	*1.13*	.....	.....
Year	.....	.....	26.96	10.14	27.94	7.70	27.28	.....	39.58	6.69	.....	.....

Evaporation from the Des Plaines watershed, as given by differences between rainfall and run-off in the preceding table.

[Inches on watershed.]

Water year.	December to May.	June to August.	September to November.	Total.
1886	.....	5.54	9.97	.....
1887	2.95	5.50	.....	.....
1889	11.80	10.08	8.05	29.93
1890	.....	.....	7.11	.....
1892	.....	7.80	5.52	.....
1893	5.32	5.34	6.16	16.82
1894	6.94	3.07	10.23	20.24
1895	.....	10.69	6.94	.....
1896	14.18	9.78	8.93	32.89

RUN-OFF OF ST. LAWRENCE RIVER.

According to the report of the Deep Waterways Commission, the area of the water surface of Lake Ontario is 7,450 square miles, and the area of the tributary watershed, exclusive of the area of the lake itself, 25,530 square miles. The total area of the drainage basin, including both land and water surfaces, is 32,980 square miles. The area of the water surface of St. Lawrence River from Gallops Rapids to Montreal[1] is given at 220 square miles, and the area of the tributary watershed at 5,710 square miles; hence the total area of the basin of the St. Lawrence from Gallops to Montreal becomes 5,930 square miles.

In the foregoing figures Lake Ontario is considered as beginning in Niagara River, at the foot of Niagara Falls and terminating at the head of Gallops Rapids, whence the following subdivisions of water-surface area are derived: Niagara River, 5 square miles; Lake Ontario proper, 7,260 square miles; St. Lawrence River, 185 square miles; giving a total, as above, of 7,450 square miles.

Of the total area of watershed of 25,530 square miles, 14,275 square miles lie within the State of New York and 11,255 square miles in the Province of Ontario. The standard low-water elevation of Lake Ontario is taken as 244.53 feet, and the standard high-water elevation as 249.04 feet above tide.

St. Lawrence River is considered as beginning at Gallops Rapids. The following table gives the elevation of water surface at a number of points.[2]

[1] Report of U. S. Deep Waterways Commission, 1897, House Document No. 192, Fifty-fourth Congress, second session, pp. 151-153.

[2] Report of U. S. Deep Waterways Commission, 1897, p. 152.

Elevation above tide of low-water and high-water surface of St. Lawrence River.

Locality.	Standard low water.	Standard high water.
	Feet.	*Feet.*
Ogdensburg	244.28	248.57
Lake St. Francis, at Valleyfield	153.50	155.94
Lake St. Louis, at Melicheville	70.0	77.50
Montreal	23.10	35.78

The area of water surface of the St. Lawrence from Gallops Rapids to Montreal is 220 square miles, and the total area of watershed not included in the surface of the river is 5,710 square miles, of which 3,800 square miles lie in New York, 620 in Ontario, and 1,290 in Quebec. The total area of the drainage basin, including water surface of the river, is 5,930 square miles.

The only measurements as to the discharge of St. Lawrence River thus far made are those of the Lake Survey, which give a mean discharge of 300,000 cubic feet per second. The recent data would indicate that this figure is somewhat too large, as in the Lake Survey discharge of Niagara River. The streams tributary to Lake Ontario, however, issue from a region of heavier rainfall than those tributary to the Upper Great Lakes and, as shown by the run-off tables of this report, are generally much better water yielders. Taking everything into account, it is probable that the minimum discharge of St. Lawrence River will not be less than from 8 to 10 inches over the entire watershed per year. A run-off of 12 inches per year over the entire drainage basin would give a mean discharge of 234,300 cubic feet per second, or a discharge of 0.884 cubic foot per square mile per second. A mean discharge of 300,000 cubic feet per second, as measured by the Lake Survey, would give 1.13 cubic feet per square mile per second. These figures are for the minimum discharge; for years, or cycles of years, of average rainfall the run-off would be more.

RUN-OFF OF INLAND STREAMS OF NEW YORK.

The data for determining the run-off of the inland streams of New York are included in the tables given on pages 67 to 85 and others following. The results of measurements on Oatka Creek, a tributary of Genesee River, with a drainage area of 27.5 square miles above the point of measurement, from April, 1890, to November, 1892, are given on page 70. The discharge of Genesee River at Mount Morris, above which point the drainage area is 1,070 square miles, from December, 1893, to November, 1896, is given on page 58. The table on pages 76 and 77 shows the quantity of water drawn from Hemlock Lake, also a tribu-

tary of Genesee River, and with a drainage area above the point of measurement of 43 square miles, for the water years 1880 to 1884, inclusive. The table on page 78 gives a similar tabulation of water drawn from Skaneateles Lake for the months indicated from October, 1890, to November, 1897, inclusive. The tables on page 82 give the run-off of Hudson River as measured at Mechanicville, where the drainage area is 4,500 square miles, from October, 1887, to November, 1896, inclusive. The table on pages 83 to 85 gives the run-off of Croton River, as measured at the Croton dam, where the drainage area is 338 square miles, for the water years from 1870 to 1896, inclusive. The table on page 72 presents measurements at Rochester in comparison with those at Mount Morris. So far as the author can learn, the foregoing include all the systematic measurements of streams, for considerable periods, thus far made in the State of New York, except those by John B. Jervis of the Madison and Eaton brooks in 1835, the results of which are presented in his report for that year to the canal commissioners.[1]

DISCHARGE MEASUREMENTS OF EATON AND MADISON BROOKS.

Eaton and Madison brooks, of which measurements were made by Mr. Jervis in 1835, are in the central-eastern part of Madison County and tributary to Chenango River. The drainage area of Eaton Brook is given by Mr. Jervis at 6,800 acres, or 10.6 square miles, and that of Madison Brook as 6,000 acres, or 9.4 square miles.

Rainfall and run-off of Eaton Brook.

Month.	Rainfall.	Rainfall for 6,800 acres.	Run-off from 6,800 acres.	Percentage of run-off to rainfall.
1835.	*Inches.*	*Cubic feet.*	*Cubic feet.*	
June	6.72	165,876,480	59,407,394	35.8
July	2.74	67,634,160	27,994,240	41.4
August	2.86	70,596,240	13,547,058	19.2
September	1.34	33,076,560	9,586,513	29.0
October	3.0	74,052,000	20,694,651	27.2
November	2.20	54,304,800	23,772,620	43.8
December	0.96	23,696,640	36,525,544	54.1
June to December, inclusive	19.82	489,236,880	191,528,020	39.2
June to October, inclusive		411,235,440	131,229,856	31.9

[1] The measurements for short periods of several streams and of the water supply of Brooklyn are not overlooked in this statement, which is intended to apply to measurements extending over a year or more.

Rainfall and run-off of Madison Brook.

Month.	Rainfall.	Rainfall for 6,000 acres.	Run-off from 6,000 acres.	Percentage of run-off to rainfall.
1835.				
Snow of November–December, 1834, on ground	*Inches.*	*Cubic feet.* 87,120,000	*Cubic feet.*	
January	2.17	47,262,600	23,192,079	49.1
February	2.50	54,450,000	35,377,594	64.9
March	1.03	22,443,400	43,284,656	192.8
April	5.0	108,900,000	80,776,974	74.1
May	1.98	43,124,400	58,013,176	134.5
June	8.05	175,329,000	20,138,006	11.5
July	3.87	84,288,600	23,141,302	27.4
August	3.06	66,646,800	23,725,060	35.6
September	0.88	19,166,400	19,158,957	99.9
October	3.86	84,070,800	19,544,880	23.2
November	2.10	45,738,000	18,232,372	39.9
December	0.76	16,552,800	19,401,364	117.2
January to December, inclusive	35.26	855,092,800	383,986,420	44.9
January to May, inclusive		363,300,400	240,644,479	66.2
June to October, inclusive		429,501,600	105,708,205	24.6

The following statements in regard to these measurements are abstracted from Mr. Jervis's report:[1] From the Eaton Brook results it appears that the average run-off from June to December, inclusive, was 39.2 per cent of the rainfall and from June to October, inclusive, 31.9 per cent of the rainfall. The minimum monthly run-off was in August, which shows only 19.2 per cent of the rainfall. The rainfall in the month of June, 1835, on Eaton Brook was 6.72 inches and in July 2.74 inches. The percentage of run-off to rainfall for June was 35.8, whereas for July it was 41.4, which would indicate that the bulk of the June rain must have been at the end of the month.

[1] For Mr. Jervis's original report see Appendix F to Ann. Rept. Canal Com., 1835, Ass. Doc. No. 65, pp. 55-60. Mr. Jervis's tables, with extracts from the report, are also quoted in the following documents:

(1) Report of F. C. Mills, chief engineer Gen. Val. Can., in Appendix D to Ann. Rept. Can. Com., 1837, Ass. Doc. No. 80, p. 81.

(2) Report of W. H. Talcott, Ees. Eng. Gen. Val. Can., 1840, Ass. Doc. No. 96, p. 51.

(3) Report of the Regents of the University, 1838, Sen. Doc. No. 52, pp. 208-211.

(4) Documentary History of the New York State Canals. By S. H. Sweet, Dep. State Eng. and Sur., 1863, Ass. Doc. No. 8, pp. 203-204.

From the measurements of Madison Brook it appears that in 1835 the average run-off for the whole year, including the snow on the ground on January 1, was 44.9 per cent, or nearly one-half of the rainfall. Mr. Jervis points out that on account of the storage of the reservoir Madison Brook record can not be taken for the summer months, but that the year should be divided into two periods. For the first period he gives the results from January to May, inclusive, during which the run-off was 66.2 per cent of the rainfall, and for the second from June to October, during which the run-off was 24.6 per cent of the rainfall. During the second period, June to October, inclusive, Eaton Brook gave a run-off of 31.9 per cent of the rainfall. Mr. Jervis explains these different results by the different characters of the two districts drained. Eaton Brook Valley is very narrow and the area drained quite steep, with a very close-textured soil. Madison Brook Valley, on the other hand, is much wider, with easy slopes, and the soil in a portion of it is more porous than that on Eaton Brook. Mr. Jervis concludes his discussion with the remark that Eaton Brook Valley would afford more than an average run-off over a large district of country including the usual varities of soil, while Madison Brook would probably not differ materially from the general average in this State.

In his documentary history of the New York State canals, which is included in the annual report of the State engineer and surveyor for the fiscal year ending September 30, 1862, S. H. Sweet analyzes Mr. Jervis's measurements of discharge of Eaton and Madison brooks and points out several probable errors, especially in the Madison Brook result, where, because the measurements indicate only what was actually discharged through the sluice pipes each day instead of what drained off from the valley, he concludes that the real drainage of the Madison Brook area in 1835 was about 0.518 of the rainfall, instead of 0.449, as given by Mr. Jervis. Inasmuch as the Eaton Brook and Madison Brook measurements have only historical interest at the present time, this branch of the subject is not here pursued at length. So far as can be learned, the measurements of these two streams by Mr. Jervis, in 1835, were the first systematic measurement of the run-off of streams in the United States. Geologically these streams lie in the horizon of the Hamilton shales.

DISCHARGE MEASUREMENTS OF OATKA CREEK.

The measurements of Oatka Creek, recorded in the following table, were made at the milldam in the south part of the village of Warsaw, in Wyoming County. The dam was new, practically tight, and well adapted for securing accurate results. Measurements were also made of the outflow of the head race way leading from the dam for different elevations of water on the dam, and a curve prepared from which the discharge of the race way was read off and added to the discharge over

the dam as computed by Francis's weir formula. It is believed that the results are accurate within a very small per cent.

Rainfall, run-off, evaporation, and mean temperature of Oatka Creek drainage area.

[In inches on the watershed.]

Months.	1890.				1891.				1892.			
	Rainfall.	Run-off.	Evaporation.	Mean temperature.	Rainfall.	Run-off.	Evaporation.	Mean temperature.	Rainfall.	Run-off.	Evaporation.	Mean temperature.
				°				°				°
December	3.33	.....	.....	37.0	2.61	0.97	.....	24.6	3.80	1.04	.....	34.9
January	4.36	.....	.....	32.7	4.12	2.62	.....	26.1	3.82	0.78	.....	21.0
February	3.63	.....	.....	31.5	4.67	3.40	.....	29.0	3.71	1.66	.....	26.9
March	2.72	.....	.....	29.5	3.70	2.87	.....	29.9	1.73	1.94	.....	26.1
April	2.82	2.17	.....	44.7	1.52	1.39	.....	45.7	1.04	2.21	.....	42.1
May	6.15	3.16	.....	52.8	1.60	0.63	.....	52.8	5.74	1.75	.....	50.0
	23.01	.....	.....	*38.0*	*18.22*	*11.88*	*6.34*	*34.7*	*19.84*	*9.38*	*10.46*	*31.8*
June	4.12	1.85	.....	67.4	4.01	0.44	.....	65.2	6.67	1.41	.....	67.2
July	3.18	0.38	.....	70.2	4.52	0.37	.....	63.9	4.18	2.06	.....	68.1
August	3.22	0.28	.....	66.8	4.25	0.25	.....	65.4	4.45	1.43	.....	67.1
	10.52	*2.51*	*8.01*	*68.1*	*12.78*	*1.06*	*11.72*	*64.8*	*15.30*	*4.90*	*10.40*	*67.5*
September	6.59	1.35	.....	60.3	1.72	0.46	.....	62.5	1.62	0.24	.....	59.0
October	4.52	2.27	.....	50.2	2.49	0.24	.....	46.6	2.19	0.33	.....	47.2
November	2.90	2.13	.....	39.3	2.91	0.41	.....	36.5	2.74	0.57	.....	35.0
	14.01	*5.75*	*8.26*	*49.9*	*7.13*	*1.11*	*6.01*	*48.5*	*6.55*	*1.14*	*5.41*	*47.1*
Year	47.54	.....	.....	48.5	38.12	14.05	24.07	45.7	41.69	15.42	26.27	45.4

The drainage area of Oatka Creek above Warsaw includes 27.5 square miles of rolling semimountainous country. The valley of the creek is deep cut, with numerous springs at the head waters. The drainage area is mostly deforested and in a high state of cultivation, the soil inclining to clay for a considerable portion. Geologically the stream lies in the rocks of the Portage formation, as developed in western New York. The run-off from this area may be taken as fairly typical of many small streams in western New York.

DISCHARGE MEASUREMENTS OF GENESEE RIVER.

The measurements of Genesee River proper, presented in the table on page 58, were made at the timber dam of the Mount Morris Hydraulic Power Company from September, 1893, to November, 1896, inclusive. The crest of this dam is quite irregular, and, in order to apply weir formulæ to it, an accurate profile was taken and the dam divided into a number of approximately level sections, with each section computed separately for various heights and advancing by 0.1 of a foot up to 10 feet. Working on this plan, the flow over the entire dam, which is 337 feet in length, was obtained by adding together the sums of the several sections at the corresponding heights and tabulating these. A gage graduated to 0.05 foot was erected on the river bridge

CANYON OF GENESEE RIVER BETWEEN MOUNT MORRIS AND PORTAGE.

a short distance away, with its zero level coinciding with the lowest point of the dam. During ordinary stages of the river readings of this gage were taken twice each day, but in time of high water, in order to obtain the movement of floods as accurately as possible, readings were taken several times a day. In order to compute the flow readily a curve was projected, embodying the data of the tabulation previously referred to, and from which, with the given gage heights, the flows in cubic feet per second could be quickly read off.

When the measurements were first begun, it was considered that the formula $Q = 1142\ H^{\frac{3}{2}}$ was best suited to the form of the dam, but after more careful consideration it was apparent that the results given by this formula were somewhat in excess of the actual discharge, especially for the low-water flows. Accordingly a weir was constructed during the summer of 1896, at a point 2.5 miles above the Hydraulic Power Company's dam, where rock bottom clear across the river offered a convenient opportunity for such construction without heavy expense. This weir was made perfectly tight.

In order to correlate the measurements at the Mount Morris Hydraulic Power Company's dam with those of the weir, two observations a day were taken at each place, nearly at the same time; that is to say, they were both taken by the same man, who passed immediately from the weir to the dam and vice versa. Observations on the weir were obtained up to a head of 4 feet, and the corresponding discharge computed with the proper allowance for velocity of approach, etc. The depths on the Hydraulic Power Company's dam corresponding to the given depths on the weir were so plotted on the diagram as to give at once the relation between the flow at the weir and the depth on the crest of the Hydraulic Power Company's dam. By proceeding in this way the dam was accurately rated up to a discharge of 5,000 cubic feet per second. For discharges beyond 5,000 cubic feet per second the original determination has been used. An extension of the plotted curves shows that some little distance above 5,000 cubic feet per second discharge the results of the two methods are substantially the same. The two curves crossed at the point of about 6,000 cubic feet per second discharge. For discharges above 10,000 or 15,000 cubic feet per second there is probably an error in the results of from 5 to 10 per cent. Below 5,000 cubic feet per second it is believed that the results are now accurate within 2 or 3 per cent. Francis's formula, $Q = 3.33\ L\ H^{\frac{3}{2}}$ has been used for the weir computations.

The measurements taken previously to the construction of the weir and the rating of the dam, as aforesaid, have all been corrected to conform to the new determinations; hence all the data of the Genesee measurements of this table may be considered as accurate within the limits stated.

Discharge measurements of Genesee River have also been kept for the last three years at Rochester, where the drainage area is about 2,400 square miles. From data obtained during the summer of 1895 it was apparent that these measurements also require a correction in order to give the approximate true flow of the stream during the period covered. Without going into detail it may be stated that the Rochester measurements in the following table give the corrected results, which are now probably accurate within from 5 to 10 per cent:

Comparison of the measurements of Genesee River at Rochester with those at Mount Morris for the water years 1894 to 1896, inclusive.

[In cubic feet per second, and with yearly means also in inches on the watershed.]

Month.	1894.			1895.			1896.		
	As per record.	Corrected.	Estimated from measurements at Mount Morris. *a*	As per record.	Corrected.	Estimated from measurements at Mount Morris. *a*	As per record.	Corrected.	Estimated from measurements at Mount Morris. *a*
December	3,914	3,914	4,797	1,459	1,100	1,256	1,839	1,700	2,710
January	2,841	2,841	2,867	1,619	1,200	1,335	1,345	1,400	964
February	2,584	2,584	1,954	977	700	495	2,702	2,702	2,005
March	6,008	6,008	6,794	4,035	4,035	3,985	3,725	3,725	6,158
April	5,646	5,646	7,172	3,083	3,083	4,257	7,623	7,623	7,172
May	6,304	6,304	9,080	1,309	900	385	1,576	1,300	347
	4,576	*4,576*	*5,477*	*2,099*	*1,848*	*1,958*	*3,181*	*3,054*	*3,218*
June	2,951	2,800	2,321	885	535	283	1,317	1,000	654
July	1,055	792	292	645	390	232	854	645	501
August	973	732	442	600	400	254	585	440	416
	1,656	*1,426*	*1,003*	*728*	*440*	*256*	*977*	*692*	*522*
September	1,664	1,500	1,963	407	250	221	324	240	327
October	1,228	920	899	366	220	230	2,271	2,000	3,667
November	1,782	1,600	1,729	834	500	993	993	745	1,728
	1,573	*1,335*	*1,523*	*534*	*333*	*478*	*1,353*	*1,006*	*1,926*
Year	3,088	2,978	3,370	1,364	1,116	1,163	2,174	1,951	2,290
Inches on watershed.	19.20	18.35	19.38	8.48	6.41	6.67	12.48	11.20	12.80

a Increased in proportion to increased drainage area at Rochester.

As interesting data from Genesee River measurements, we may discuss the flood of May 20–23, 1894, at which time the approximate discharge of the stream at Mount Morris, from a drainage area of 1,070 square miles, was as follows:

Discharge of Genesee River at Mount Morris during the flood in May, 1894.

	Cubic feet per second.
May 18, 7 a. m	600
May 18, 6 p. m	3,090
May 19, 7 a. m	5,530
May 19, 6 p. m	5,090
May 20, 7 a. m	16,580
May 20, 12 m	22,210

Discharge of Genesee River at Mount Morris during the flood in May, 1894—Cont'd.

	Cubic feet per second.
May 20, 6 p. m	28,000
May 21, 3.30 a. m	42,000
May 21, 7 a. m	33,000
May 21, 12 m	30,730
May 21, 6 p. m	26,500
May 22, 7 a. m	15,650
May 22, 12 m	13,650
May 22, 6 p. m	10,720
May 23, 7 a. m	7,300
May 23, 12 m	6,700
May 23, 6 p. m	5,690
May 24, 7 a. m	5,390

The total run-off from 7 a. m. of May 19 to 7 a. m. of May 24 was nearly 6,900,000,000 cubic feet.

On the morning of May 21 the flats in the broad, level valley of

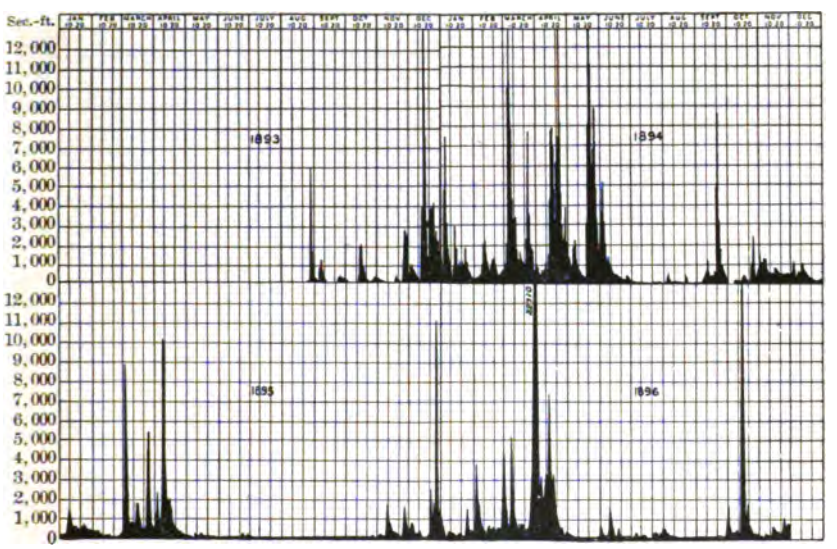


FIG. 2.—Discharge of Genesee River at Mount Morris, New York, 1893 to 1896.

Genesee River and Canaseraga Creek, between Dansville, Mount Morris, and Rochester, and which have an area of from 60 to 80 square miles, were nearly flooded, in some localities to a depth of from 4 to 6 feet. On account of the large pondage by these flats, although the maximum run-off at Mount Morris was 42,000 cubic feet per second at 3.30 a. m. on the morning of May 21, at Rochester the maximum flow did not at any time exceed about 20,000 cubic feet per second. We have, then, a case where a large pondage has, by prolonging the time of run-off, modified a flood flow over 50 per cent. As further illustrating the effect of a large reservoir, or, what is the same thing, the effect of a large pond area in modifying the effect of an extreme

flood, reference may be made to fig. 3, in which, with time as abscissas and run-off as ordinates, the run-off record of Genesee River for May 18–24, 1894, has been plotted. The lower curve of that figure may be taken as representing approximately the law of the run-off of any generally distributed heavy rainfall on the catchment area of this stream. In making this statement it is not overlooked that flood flows at other seasons of the year may differ somewhat in their movement from that of May, 1894. Inasmuch as the rapidity and intensity of the run-off of any given stream depend largely upon the topography, the statement may be made that the general law of movement of floods in Genesee River is indicated by the lower curve of fig. 3. With this understanding we may assume any other run-off and construct the approximate curve by drawing it generally parallel to the curve of the actually observed case. In this way the upper curve of fig. 3, representing the curve of a flood one and one-half times greater than that of May, 1894, has been produced, slight irregularities of the lower curve having been neglected in projecting the upper one.

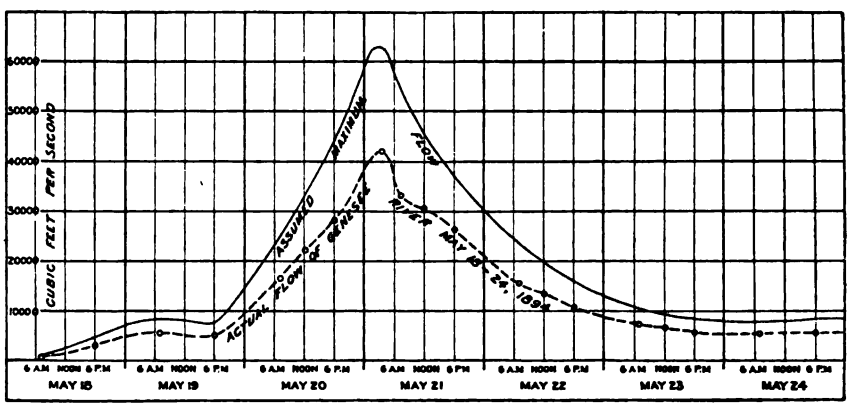


FIG. 3.—Flood flow of Genesee River, May 18-24, 1894.

A flood flow one and one-half times as great as that of May, 1894, which culminated in a maximum of about 42,000 cubic feet per second at 2.30 a. m. of May 21, gives a maximum of 63,000 cubic feet per second, the movement of which would be, under the assumptions, substantially as in the upper curve of fig. 3. As to the probability of a maximum flood flow of 63,000 cubic feet per second on the upper Genesee drainage area, the case of the neighboring Chemung River may be cited, where a flood flow of 67.1 cubic feet per second per square mile occurred in June, 1889. This figure applied to the upper Genesee would give a possible maximum run-off of 71,126 cubic feet per second.

Geologically, the drainage area of Genesee River above Mount Morris, the point of measurement, lies in the shales, sandstones, etc., of the Portage and Chemung groups. Its extreme head waters south

of the Pennsylvania line issue from the lower Carboniferous. Generally the soils throughout the whole basin are heavy and tenacious, inclining to clay. Their capacity for absorbing and retaining water must, therefore, be considered as small.

DISCHARGE MEASUREMENTS OF HEMLOCK LAKE.

Measurements of the run-off of the Hemlock Lake drainage area for the water years 1880 to 1884, inclusive, were made by the Rochester Waterworks. Hemlock Lake lies at an elevation of 896 feet above tide, and has a length of 6.5 miles, with an average width of about 0.5 of a mile. The area of the surface at low water is 1,828 acres. The total drainage basin, including the area of the lake, is 27,554 acres, or about 43 square miles. The shores are bold, and on the east side rise to a height of several hundred feet above the lake in a distance of 2 or 3 miles. At the head of the lake there is a swamp of 118 acres, partially covered at high water.

The outflow of the lake during the period covered by the measurements included in the following table may be considered as having taken place at three points: (1) At the natural outlet of the lake; (2) at an artificial channel through which water was discharged at will for the benefit of the millers on the outlet; and (3) through the conduit of the Rochester waterworks. The run-offs given are the sums of these several outgoes. In order to determine the outflow of the natural outlet, a weir was constructed and the discharge observed at different heights of the lake surface. The discharge into the artificial channel was through submerged orifices of known dimensions, and has been computed from standard formulæ for the discharge of such orifices, the size of the openings and the difference of level of water surfaces above and below being known.

The discharge of the conduit of the Rochester waterworks is as computed from standard formulæ for discharge through pipes. Measurements made by the author and others during the last few years show that the computed quantities passing through the conduit were not far from correct. As a whole, it is believed that the Hemlock Lake results are accurate within from 5 to 8 per cent.

Water drawn from Hemlock Lake for the water years 1880 to 1884, inclusive.

[In inches on the watershed.]

Month.	1880.					1881.				
	Mean monthly elevation of lake surface.	Rainfall.	Water drawn.	Rainfall, less the water drawn.	Temperature.	Mean monthly elevation of lake surface.	Rainfall.	Water drawn.	Rainfall, less the water drawn.	Temperature.
December	−1.67	1.26	0.16	.....	a 31.4	−1.33	0.72	0.49	.....	27.3
January	−0.91	1.37	0.15	.....	a 25.5	−1.47	2.24	0.44	.....	24.7
February	−0.11	1.45	0.16	.....	a 27.3	−0.11	1.08	0.54	.....	29.7
March	+0.21	1.47	0.15	.....	a 31.8	+1.20	1.92	1.73	.....	39.1
April	+0.79	1.25	0.15	.....	a 45.7	+1.47	0.52	1.24	.....	45.2
May	+0.87	2.08	0.17	.....	71.8	+1.32	2.23	1.11	.....	69.7
	−0.14	*8.88*	*0.94*	*7.94*	*58.9*	*+0.18*	*8.71*	*5.55*	*3.16*	*39 3*
June	+0.45	1.66	0.36	.....	76.5	+1.08	3.13	0.76	.....	73.9
July	−0.15	1.93	0.41	.....	77.1	+0.58	3.71	0.43	.....	75.6
August	−0.70	3.46	0.35	.....	74.4	.....	0.95	0.50	.....	80.0
	−0.13	*7.05*	*1.12*	*5.93*	*76.0*	*+0.55*	*7.79*	*1.69*	*6.10*	*76.5*
September	−1.13	1.35	0.31	.....	69.7	−0.69	1.73	0.35	.....	77.9
October	−1.57	3.85	0.31	.....	53.4	−0.81	4.23	0.33	.....	59.1
November	−1.24	0.86	0.39	.....	37.1	−0.71	1.81	0.46	.....	44.8
	−1.31	*6.06*	*1.01*	*5.05*	*53.4*	*−0.74*	*7.77*	*1.14*	*6.63*	*60.6*
Year	−0.43	21.99	3.07	18.92	51.8	+0.04	24.27	8.38	15.89	53.9

a Interpolated from average of fifteen years.

Month.	1882.					1883.				
	Mean monthly elevation of lake surface.	Rainfall.	Water drawn.	Rainfall, less the water drawn.	Temperature.	Mean monthly elevation of lake surface.	Rainfall.	Water drawn.	Rainfall, less the water drawn.	Temperature.
December	−0.05	4.02	0.66	.....	39.8	−1.51	0.91	0.19	.....	31.0
January	+1.63	1.03	2.04	.....	29.4	−1.56	0.84	0.21	.....	25.7
February	+1.39	1.07	1.40	.....	37.0	+0.08	3.11	0.28	.....	30.6
March	+1.67	1.47	2.82	.....	38.7	+0.95	0.90	0.68	.....	33.3
April	+1.51	2.49	1.53	.....	48.5	+1.57	2.43	1.58	.....	47.8
May	+1.61	5.20	1.74	.....	57.4	+1.59	9.54	2.59	.....	59.1
	+1.29	*15.37*	*10.19*	*5.18*	*41.8*	*+0.18*	*17.73*	*5.53*	*12.20*	*37.9*
June	+1.45	2.31	1.85	.....	71.9	+1.38	4.52	1.65	.....	74.2
July	+0.81	1.42	0.62	.....	78.0	+1.29	2.13	1.08	.....	75.7
August	+0.15	2.17	0.41	.....	76.8	+0.64	2.86	0.45	.....	73.7
	+0.80	*5.90*	*2.88*	*3.02*	*75.6*	*+1.10*	*9.51*	*3.18*	*6.33*	*74.5*
September	−0.44	1.78	0.43	.....	69.4	+0.25	2.38	0.21	.....	65.1
October	−0.99	1.00	0.65	.....	61.4	+0.07	1.62	0.18	.....	55.7
November	−1.38	1.41	0.36	.....	41.8	+0.17	2.02	0.19	.....	45.1
	−0.94	*4.19*	*1.44*	*2.75*	*57.5*	*+0.16*	*6.00*	*0.58*	*5.42*	*55.3*
Year	+0.61	25.46	14.51	10.95	54.2	+0.41	33.24	9.29	23.95	51.4

Water drawn from Hemlock Lake for the water years 1880 to 1884, etc.—Cont'd.

Month.	1884.				
	Mean monthly elevation of lake surface.	Rainfall.	Water drawn.	Rainfall, less the water drawn.	Temperature.
December	+0.44	2.01	0.54	.....	34.0
January	+0.46	1.78	1.01	.....	24.7
February	+1.28	2.17	2.70	.....	30.2
March	+1.47	3.18	2.71	.....	30.5
April	+1.56	2.21	1.47	.....	42.7
May	+1.62	3.30	1.69	.....	56.7
	+1.14	*14.65*	*10.12*	*4.53*	*36.5*
June	+1.01	2.44	0.75	.....	70.4
July	+0.58	3.98	0.37	.....	68.4
August	+0.27	1.08	0.24	.....	70.8
	+0.62	*7.50*	*1.36*	*6.14*	*69.9*
September	—0.26	2.24	0.71	.....	66.9
October	—0.70	1.34	0.20	.....	52.3
November	—1.17	1.01	0.18	.....	38.9
	—0.71	*4.59*	*1.09*	*3.50*	*52.7*
Year	+0.55	26.74	12.57	14.17	48.9

The drainage area of Hemlock Lake is, as stated, 27,554 acres, and the area of the lake itself at the elevation ±0.0 is 1,828 acres; hence the lake surface is 6.6 per cent of the total drainage area, or the drainage area is 15.1 times the area of the lake surface. On this basis 1 inch on the whole area is 15.1 inches on the lake. Taking into account these statements, it is clear that the data of the table give approximately the natural run-off, although for exact figures corrections for actual elevations of lake surface at the beginning, as well as at the end of each year, should be applied. On this point see the discussion on the minimum flow of Hemlock Lake, on pages 92 and 93. Geologically, the Hemlock Lake Basin proper is in the Hamilton and Marcellus shale, with the hills at the side rising into the rocks of the Portage group.

DISCHARGE MEASUREMENTS OF SKANEATELES LAKE.

The measurements of the run-off of Skaneateles Lake drainage area, as given in the following table, have been made by the Syracuse waterworks over a dam at the foot of the lake or over a weir a short distance below since October, 1890. Previous to 1886 this lake was the principal feeder of the Jordan level of Erie Canal, but in that year Otisco and Owasco lakes were also made feeders. The Skaneateles Lake dam was reconstructed 9 feet high by the State in 1887, and in 1893 was again rebuilt by the Syracuse water board with its spillway 2 feet higher than the crest of the old dam. The area of the water surface of Skaneateles Lake is 12.75 square miles, and the area of the watershed, including the area of the lake, is 73 square miles.

The elevation above tide is 867 feet. The lake lies in a deep valley, with bold shores rising several hundred feet at either side. The figures given in the following table do not represent in any degree the natural run-off of this drainage area, but merely the water yield during the years indicated, in which there was large storage.

In March, 1895, the city of Syracuse began to draw water through its new conduit to Skaneateles Lake. Since that time the results given in the table are the quantity flowing in the outlet as measured on the weir located at Willow Glen plus the outflow through the conduit. Previous to March, 1895, the results are from measurements at the dam at the foot of the lake. The earlier results are possibly affected by errors of from 12 to 15 per cent, while the latter are probably accurate within from 2 to 5 per cent. Geologically the drainage basin of Skaneateles Lake is in the Hamilton group of rocks.

Water drawn from and monthly elevatians of Skaneateles Lake for the months indicated for the water years 1890 to 1897, inclusive.

[Water drawn in inches on the watershed.]

Year, etc.	Dec.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Total.
1890:													
Mean lake surface	−1.92	−2.08	−2.25	+0.33	+0.33	+0.25	+0.37	+0.50	−0.42	−1.33	−1.08	−1.16	....
Water drawn	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	1.59	1.67	.....
1891:													
Mean lake surface	−1.00	−1.50	−1.00	+0.16	+0.50	0.0	−0.75	−1.42	−2.21	−3.25	−4.12	−5.25	.....
Water drawn	1.62	1.63	1.52	2.42	2.57	a1.90	1.23	1.33	1.93	1.79	1.61	1.21	20.76
1892:													
Mean lake surface	−5.79	−5.50	.....	−5.0	−3.67	−1.83	−0.67	−0.33	−0.67	−1.08	−1.83	−2.58	.....
Water drawn	.....	.....	.....	.....	.....	.....	.....	.....	.....	1.35	1.24	1.13	.....
1893:													
Mean lake surface	−2.56	−2.71	−2.92	−2.75	−1.33	0.0	+0.33	−0.67	−1.42	−2.17	−3.00	−3.83	.....
Water drawn	1.09	0.87	0.87	1.10	1.18	3.06	2.10	1.98	[1]1.53	1.08	1.58	1.58	20.02
1894:													
Mean lake surface	−4.75	−4.48	.....	.....	.....	−2.50	−1.27	+0.25	−0.06	−0.88	−1.00	−1.21	.....
Water drawn	1.38	0.86	.....	.....	.....	0.26	0.15	0.57	1.07	1.39	1.46	1.44	.....
1895:													
Mean lake surface	−1.58	−1.20	−1.75	−0.37	−0.17	+0.14	−0.40	−0.92	−1.67	−2.18	−3.12	−4.14	.....
Water drawn	0.32	0.24	0.22	1.29	2.55	2.14	1.64	1.77	1.87	1.64	1.85	1.75	17.23
1896:													
Mean lake surface	−4.56	−4.33	−4.60	−4.08	−2.42	−1.35	−1 58	−1.94	−2.23	−2.94	−3.42	−3.85	.....
Water drawn	1.58	1.51	1.48	1.61	1.50	1.59	1.61	1.51	1.50	1.51	1.50	1.38	18.26
1897:													
Mean lake surface	−3.92	−4.12	−4.29	−4.56	−3.46	−2.67	−2.50	−2.65	.....	.....	.....	.....	.....
Water drawn	1.35	1.25	1.08	1.06	0.26	1.12	1.34	1.45	2.21	1.41	1.61	1.47	15.61

a Interpolated. No record. Mean of preceding and following months used.

DISCHARGE MEASUREMENTS OF HUDSON RIVER.

Measurements of the flow of Hudson River have been made over the dam of the Duncan Company, at Mechanicville. In 1887 this company began daily measurement of the amount of water flowing in Hudson River at their mill.[1] With the exception of one or two days this record has been kept for every working day since October 1, 1887. A record has also been kept of the number, size, and kind of turbine water wheel in use for the same period. The Duncan Company placed all this material at the disposal of the survey of the Upper Hudson Valley, of which the author has had charge, thus enabling him to compute the mean daily flow of the river for each working day from October 1, 1887, to November 30, 1896. The flow of Sundays and holidays, when no observations were taken, has been assumed as a mean between the preceding Saturday and the following Monday, etc. The dam is a substantial structure of masonry 16 feet high, with a length of 794 feet between the abutments. The crest is stated by John R. Kaley, the constructing engineer, to be perfectly level, and from all that can be learned it appears that the daily observations have been taken with such care as to leave no reason for doubting that this is a fairly accurate exhibit of the daily flow of the stream for the period covered. This record is therefore considered to be accurate within from 5 to 8 per cent.

The greatest depth on this dam in the nine-year period, 1888 to 1896, inclusive, occurred May 5, 1893, when the gage showed a depth of 7.83 feet and the mean flow of the day was over 53,000 cubic feet per second. The drainage area of Hudson River above the Mechanicville dam is taken at 4,500 square miles.

Experience in flows over dams of this length and with depths as great as from 7 to 8 feet is as yet rather limited in this country, and the question was raised as to the best method of computing the discharge for a case like the one under discussion. The engineers of the British Government in India have had, in connection with their large irrigation works, perhaps more experience in this class of measurement than all others combined, and the formulæ used by them appear more rational in form than those commonly used in the United States for such computations, and after some study it was decided to use these. As many American engineers may not be familiar with these formulæ they are here reproduced. They take the following form:

$$Q = \tfrac{2}{3} L C \sqrt{2g} d^{\frac{3}{2}}, \qquad (1)$$

in which—

Q = the discharge over a thin-edged clear overfall, in cubic feet per second,

L = the length of the dam in linear feet,

[1] Annual Report of the State Engineer and Surveyor of New York, 1895, p. 104.

C = coefficient depending for its value on d,
g = acceleration of gravity = 32.2,
d = depth on crest, in linear feet.

Equation (1) may also take the form—

$$Q = 5.35\ L\ C\ \sqrt{d^3}. \tag{2}$$

To find C for different values of d, we have—

$$C = 1 - \left(\frac{0.04\ (34.6 + d)}{4}\right). \tag{3}$$

This gives a series of values of C corresponding to d. For instance, for $d = 0.25$ foot, $C = 0.651$; for $d = 0.50$ foot, $C = 0.649$, and so on.

For a wide-crested dam the coefficient is further modified to suit the actual width of the crest. For this we have given the expression—

$$C' = C - \left(\frac{0.025\ C\ (B + 1)}{1 + d}\right), \tag{4}$$

in which—

B = the width of the crest in linear feet;
C = the coefficient for a thin-edged weir, corresponding to a depth d, as per equation (3), and
C′ = the adjusted coefficient corresponding to a given breadth B and a depth d.[1]

In the case of the Mechanicville dam we have a stone crest 7 feet in width and slightly inclined upstream. The width of the river a short distance above the dam is considerably over 800 feet; the depth for some distance back is from 16 to 20 feet. In order to avoid a correction for velocity of approach, a crest was assumed 5 feet wide and values of C′ were computed on that basis.

Having obtained values of C′ for $d = 0.25, 0.50, 0.75, 1.00, 1.25, 1.50, 1.75$ feet, and so on up to 8 feet, corresponding values of Q were computed and plotted at a large scale as a curve with values of d as abscissas and the corresponding flows as ordinates. From this curve intermediate values of Q have been read off.

[1] The method of deducing equations (3) and (4) may be found in Mullin's Irrigation Manual, 1890, pp. 11, 12, 138, 139, 171, 172.

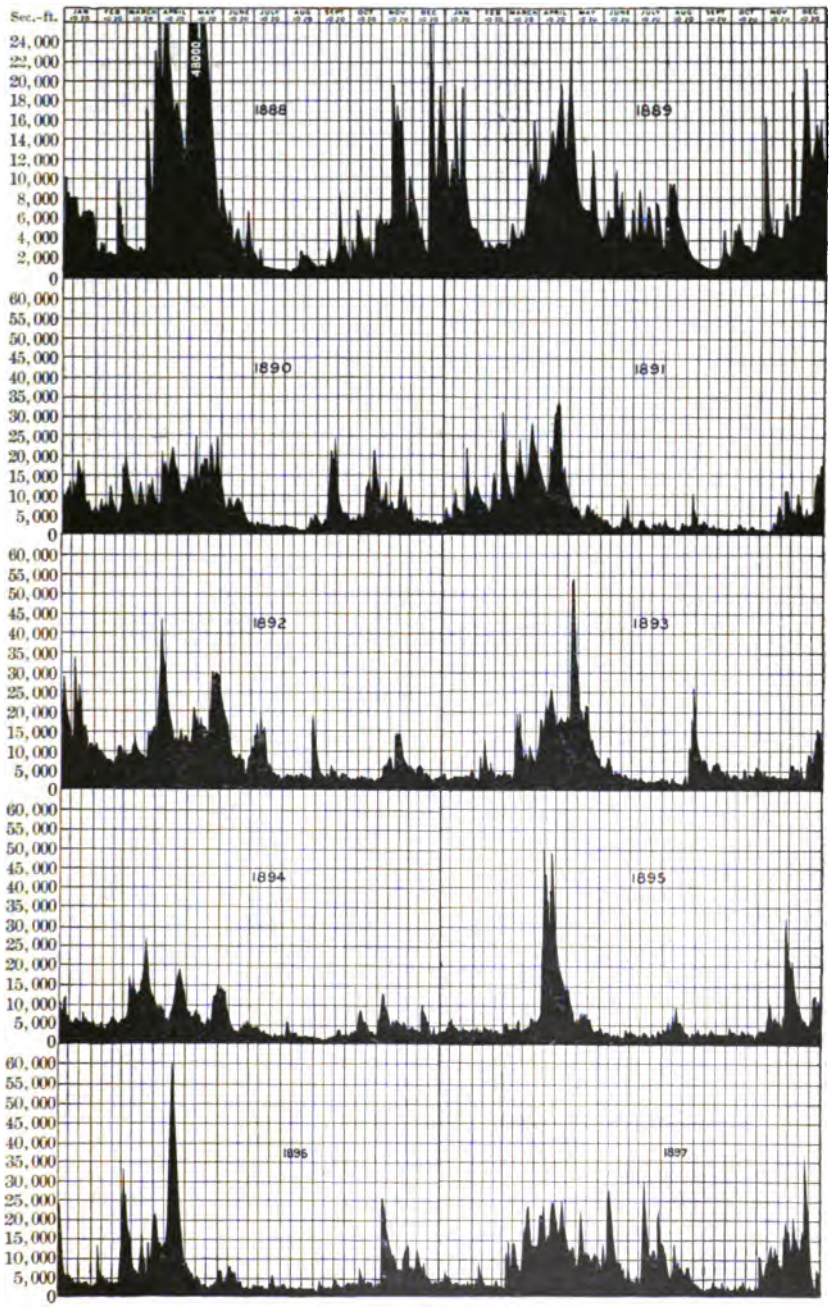


FIG. 4.—Discharge of Hudson River at Mechanicville, New York, 1888 to 1897.

Run-off of Hudson River at Mechanicville from October, 1887, to November, 1896, inclusive. (a)

[In cubic feet per second.]

Month.	1887.	1888.	1889.	1890.	1891.	1892.	1893.	1894.	1895.	1896.
December		8,018	10,014	13,226	3,244	8,577	4,031	7,217	4,367	10,899
January		6,367	10,983	11,272	8,284	18,857	3,192	6,757	3,876	6,787
February		3,714	3,790	7,913	11,664	9,263	4,805	4,836	3,543	4,668
March		6,845	8,280	11,129	17,736	10,929	8,250	14,738	4,204	13,600
April		21,200	13,690	15,053	20,021	21,554	17,889	11,135	23,822	24,972
May		21,420	8,871	17,931	5,533	19,622	22,285	7,506	6,850	4,610
Mean		*11,389*	*9,337*	*12,921*	*11,021*	*14,851*	*10,114*	*8,759*	*7,759*	*10,921*
June		4,917	6,869	7,302	3,200	12,396	4,801	7,097	2,816	4,738
July		1,537	5,727	1,950	2,337	9,287	2,521	3,168	2,559	2,772
August		1,725	4,272	2,019	2,666	5,485	5,005	2,456	3,901	2,442
Mean		*2,726*	*5,718*	*3,743*	*2,957*	*9,019*	*4,102*	*4,209*	*3,095*	*3,317*
September		2,851	1,963	8,844	2,040	4,448	6,870	1,889	2,629	2,879
October	2,365	4,608	3,740	9,215	1,472	2,819	3,865	3,649	2,631	4,106
November	4,190	10,642	7,888	9,121	4,088	7,604	3,639	6,379	8,421	11,352
Mean		*6,018*	*4,522*	*9,061*	*2,521*	*4,934*	*4,781*	*3,969*	*4,539*	*6,112*
Yearly mean		7,820	7,197	9,597	6,867	10,909	7,271	6,418	5,780	7,818

[In inches on the watershed.]

December		2.05	2.57	3.39	0.83	2.27	1.03	1.85	1.12	2.79
January		1.62	2.81	2.89	2.12	4.83	0.82	1.73	0.99	1.74
February		0.89	0.88	1.83	2.70	2.22	1.09	1.12	0.82	1.12
March		1.75	2.12	2.85	4.55	2.80	2.11	3.78	1.08	3.49
April		5.26	3.39	3.73	4.97	5.35	4.44	2.76	5.91	6.20
May		5.49	2.27	4.59	1.42	5.03	5.71	1.94	1.76	1.18
Total		*17.06*	*14.04*	*19.28*	*16.59*	*22.50*	*15.20*	*13.18*	*11.63*	*16.52*
June		1.22	1.70	1.83	0.79	3.08	1.19	1.76	0.70	1.18
July		0.39	1.47	0.50	0.60	2.38	0.65	0.81	0.66	0.72
August		0.44	1.09	0.52	0.68	1.41	1.28	0.63	1.00	0.63
Total		*2.05*	*4.26*	*2.85*	*2.07*	*6.87*	*3.12*	*3.20*	*2.36*	*2.53*
September		0.71	0.49	2.19	0.51	1.10	1.70	0.47	0.65	0.71
October	0.61	1.18	0.96	2.36	0.38	0.72	0.99	0.94	0.69	1.05
November	1.04	2.64	1.96	2.26	1.01	1.89	0.90	1.58	2.08	2.82
Total		*4.53*	*3.41*	*6.81*	*1.90*	*3.71*	*3.59*	*2.99*	*3.42*	*4.58*
Yearly total		23.64	21.71	28.56	20.56	33.08	21.90	19.37	17.46	23.63

a Annual Report of the State Engineer and Surveyor of New York, 1895, pp. 107, 120.

DISCHARGE MEASUREMENTS OF CROTON RIVER.

The record of the run-off of Croton River as measured at the old Croton dam for the water years 1870 to 1896, inclusive, is given in the table on pages 83 to 85. The watershed of the Croton consists of a broken, hilly country with its surface soil composed principally of sand and gravel. Clay, hardpan, and peat, while found in a few localities, are for the whole area only present to a limited extent. The rock formation consists generally of gneiss, although strata of limestone, some micaceous and talcose slates, with veins of granite, serpentine, and

iron ore, occur in a few places. The drainage area lies almost entirely in the State of New York, only a small portion being in Connecticut. It amounts to about 338 square miles above the old Croton dam and to 360 square miles above the new Croton dam under construction. The main river is formed by three branches, known, respectively, as East, Middle, and West branches, which, rising in the southern part of Dutchess County, flow south through Putnam County and unite near its south boundary. The river then flows across Westchester County to Hudson River, into which it empties at Croton Point, about 30 miles north of the city of New York. The principal tributaries aside from East, Middle, and West branches are Kisko, Titicus, Cross, and Muscoot rivers. The monthly and annual rainfall of the Croton watershed, as well as the run-off of the water years, from 1870 to 1896, inclusive, are given in the following table. The average annual rainfall for this period was 48.10 inches and the run-off 24.65 inches.[1]

Rainfall and run-off of Croton River drainage area from 1870 to 1896, inclusive.

[In inches on the watershed.]

Month.	1870.		1871.		1872.		1873.		1874.		1875.	
	Rainfall.	Run-off.	Rainfall.	Run-off.	Rainfall.	Run-off.	Rainfall.	Run-off.	Rainfall.	Run-off.	Rainfall.	Run-off.
December	5.96	3.07	1.49	0.64	2.59	2.11	3.68	1.45	4.13	3.38	1.78	0.98
January	4.51	3.99	3.80	0.59	1.44	2.08	5.66	4.29	6.96	8.22	2.74	0.65
February	6.40	4.28	3.81	2.21	1.22	1.25	3.09	1.72	2.78	2.79	3.47	4.09
March	3.80	3.56	4.27	3.52	2.59	1.75	3.08	4.03	1.57	3.03	4.99	3.24
April	5.45	4.11	3.01	2.02	3.04	3.11	3.77	7.12	6.31	3.63	3.04	5.58
May	2.30	1.86	3.45	2.06	3.69	1.29	2.91	2.19	1.99	3.19	1.06	1.86
	28.42	*20.87*	*19.83*	*11.04*	*14.57*	*11.59*	*22.19*	*20.80*	*23.74*	*24.24*	*17.10*	*16.40*
June	2.06	0.83	5.73	1.43	4.00	1.22	0.71	0.54	3.57	0.92	3.02	0.59
July	3.43	0.51	5.07	0.73	4.34	0.61	2.21	0.49	5.98	1.43	3.10	0.58
August	5.10	0.51	5.24	0.85	5.99	1.64	5.73	0.71	2.75	0.89	10.33	5.80
	10.59	*1.85*	*16.04*	*3.01*	*14.33*	*3.47*	*8.65*	*1.74*	*12.30*	*3.24*	*16.45*	*6.97*
September	2.85	0.35	1.44	0.63	3.69	1.25	3.73	0.52	3.56	0.58	2.11	0.90
October	4.73	0.42	6.18	1.92	2.15	1.13	5.13	1.45	2.40	0.81	3.61	0.85
November	2.51	0.62	4.35	3.41	4.91	2.67	3.72	1.81	2.72	0.74	4.61	2.05
	10.09	*1.39*	*11.97*	*5.96*	*10.75*	*5.05*	*12.58*	*3.78*	*8.68*	*2.13*	*10.33*	*3.80*
Total	49.10	24.11	47.84	20.01	39.65	20.11	43.42	26.32	44.72	29.61	43.88	27.17

1 See Wegmam's History of the Water Supply of the City of New York, Chap. IX, The Croton watershed.

Rainfall and run-off of Croton River drainage area from 1870 to 1896, etc.—Cont'd.

Month.	1876.		1877.		1878.		1879.		1880.		1881.	
	Rainfall.	Run-off.	Rainfall.	Run-off.	Rainfall.	Run-off.	Rainfall.	Run-off.	Rainfall.	Run-off.	Rainfall.	Run-off.
December	1.56	1.84	2.35	1.19	1.52	1.97	8.74	7.23	4.26	2.03	2.49	0.54
January	1.42	1.59	2.68	0.84	4.49	2,85	2.52	1.45	4.00	2.75	4.19	0.76
February	4.91	3.65	0.80	1.55	3.65	3.92	2.85	2.77	2.92	2.99	5.28	4.32
March	6.33	7.16	7.66	6.97	3.10	3.89	4.96	4.30	4.51	3.01	6.14	6.09
April	4.43	6.39	2.35	3.02	2.85	1.69	5.10	5.12	3.99	2.09	1.67	1.88
May	3.99	2.03	0.85	0.89	4.97	1.57	2.45	1.77	1.17	0.98	3.74	1.39
	23.64	*22.66*	*16.69*	*14.46*	*20.58*	*15.89*	*26.62*	*22.64*	*20.85*	*13.85*	*23.51*	*14.98*
June	2.52	0.71	4.95	0.62	4.65	1.52	5.29	0.94	1.28	0.52	5.72	1.67
July	3.42	0.55	4.65	0.51	4.28	0.74	5.95	0.73	5.65	0.54	2.45	0.58
August	1.20	0.50	2.54	0.49	2.66	0.68	5.83	1.48	3.60	0.52	1.71	0.52
	7.14	*1.76*	*12.14*	*1.62*	*11.59*	*2.94*	*17.07*	*3.15*	*10.53*	*1.58*	*9.88*	*2.77*
September	5.21	0.37	1.49	0.34	6.61	2.13	3.43	1.09	2.69	0.50	0.75	0.51
October	1.50	0.38	8.38	1.14	3.78	0.93	0.95	0.67	3.25	0.51	3.65	0.52
November	3.40	0.71	8.16	4.18	4.36	2.09	2.49	0.82	2.97	0.57	4.50	0.48
	10.11	*1.46*	*19.03*	*5.66*	*14.75*	*5.15*	*6.87*	*2.58*	*8.91*	*1.58*	*8.90*	*1.51*
Total	39.89	25.88	46.86	21.74	46.92	23.98	50.56	28.37	40.29	17.01	42.29	19.26

Month.	1882.		1883.		1884.		1885.		1886.		1887.	
	Rainfall.	Run-off.	Rainfall.	Run-off.	Rainfall.	Run-off.	Rainfall.	Run-off.	Rainfall.	Run-off.	Rainfall.	Run-off.
December	6.53	1.73	2.68	1.29	3.45	0.64	7.34	3.78	3.84	2.09	4.29	1.19
January	4.41	2.40	2.80	1.06	5.07	2.14	5.59	4.12	5.24	3.42	5.68	2.74
February	5.96	4.23	5.21	3.81	6.31	4.95	4.66	2.44	5.20	4.89	6.01	4.98
March	4.58	4.74	1.67	3.03	4.82	5.01	1.29	2.05	3.86	2.50	3.60	3.69
April	1.36	1.43	3.94	2.73	2.96	3.00	2.09	2.62	3.61	4.51	3.47	3.26
May	6.30	2.20	2.86	1.38	4.33	1.91	2.44	1.58	4.54	2.15	0.32	1.30
	29.14	*16.73*	*19.16*	*13.30*	*26.94*	*17.65*	*23.41*	*16.59*	*26.29*	*19.56*	*23.37*	*17.16*
June	3.04	1.70	5.64	0.63	2.04	0.70	1.19	0.59	3.09	0.78	7.70	1.16
July	3.63	0.69	4.26	0.52	6.54	0.81	5.27	0.52	4.40	0.61	13.32	2.63
August	3.92	0.52	2.09	0.52	4.50	1.18	7.35	0.58	3.21	0.58	7.06	3.56
	10.59	*2.91*	*11.99*	*1.67*	*13.08*	*2.69*	*13.81*	*1.69*	*10.71*	*1.97*	*28.08*	*7.35*
September	14.33	3.25	2.45	0.51	1.69	0.74	1.09	0.42	2.30	0.51	2.00	0.90
October	3.33	2.27	6.99	0.66	3.74	0.57	5.19	0.55	2.28	0.52	3.12	1.03
November	1.66	0.96	1.79	0.69	4.37	0.98	5.99	2.19	5.57	0.88	2.69	0.95
	19.32	*6.48*	*11.23*	*1.86*	*9.80*	*2.29*	*12.27*	*3.16*	*10.15*	*1.91*	*7.81*	*2.88*
Total	59.05	26.12	42.38	16.83	49.82	22.63	49.49	21.44	47.15	23.44	59.26	27.39

Rainfall and run-off of Croton River drainage area from 1870 to 1896, etc.—Cont'd.

Month.	1888.		1889.		1890.		1891.		1892.		1893.	
	Rainfall.	Run-off.	Rainfall.	Run-off.	Rainfall.	Run-off.	Rainfall.	Run-off.	Rainfall.	Run-off.	Rainfall.	Run-off.
December	6.71	2.48	6.13	5.26	2.94	4.55	3.71	1.65	5.65	1.64	1.11	1.48
January	5.56	4.01	5.14	4.41	2.03	2.34	9.76	6.84	5.95	5.07	3.29	1.70
February	5.07	4.95	2.33	2.36	4.94	3.19	6.02	5.73	1.22	1.54	4.60	3.27
March	6.44	4.69	1.86	2.10	5.66	4.72	3.36	4.37	2.90	2.10	4.52	7.21
April	2.68	4.85	4.42	2.58	3.03	3.29	3.77	2.90	1.08	1.42	3.55	3.57
May	6.27	2.67	3.22	1.76	5.74	2.73	1.36	0.89	5.74	1.62	8.18	6.06
	32.73	*23.65*	*23.10*	*18.47*	*24.34*	*20.83*	*27.98*	*22.38*	*22.54*	*13.39*	*25.25*	*23.29*
June	2.00	1.39	4.51	1.43	3.56	1.53	1.81	0.63	3.84	1.15	2.43	0.96
July	2.43	0.67	7.74	1.63	5.46	0.71	2.97	0.40	5.05	0.70	2.38	0.40
August	6.87	1.11	2.90	4.03	4.70	0.59	5.61	0.31	6.12	0.90	7.06	0.72
	11.30	*3.17*	*15.15*	*7.09*	*13.72*	*2.83*	*10.39*	*1.54*	*15.01*	*2.75*	*11.87*	*2.09*
September	10.77	3.11	6.13	2.27	6.86	2.04	1.87	0.38	2.65	0.51	2.65	0.53
October	4.80	2.58	4.85	1.93	7.63	3.36	2.15	0.41	0.92	0.17	6.42	1.17
November	4.49	3.04	8.45	5.29	1.12	2.09	3.86	0.64	7.85	1.58	3.32	2.08
	20.06	*8.73*	*19.43*	*9.49*	*15.61*	*7.49*	*7.88*	*1.43*	*11.42*	*2.26*	*12.39*	*3.78*
Total	64.09	35.55	57.68	35.05	53.67	31.14	46.25	25.15	48.97	18.40	49.51	29.15

Month.	1894.		1895.		1896.		Mean.	
	Rainfall.	Run-off.	Rainfall.	Run-off.	Rainfall.	Run-off.	Rainfall.	Run-off.
December	5.34	4.12	4.43	2.57	4.88	1.30	.....	.....
January	3.40	1.77	3.63	3.42	1.52	2.06	.....	.....
February	5.01	2.15	3.34	1.04	6.65	4.33	.....	.....
March	1.62	5.21	1.88	3.87	8.20	7.90	.....	.....
April	3.07	2.44	5.63	4.22	0.96	3.05	.....	.....
May	6.67	1.88	2.41	1.33	3.09	0.87	.....	.....
	25.11	*17.57*	*21.32*	*16.45*	*25.30*	*19.51*	*23.44*	*18.00*
June	1.69	1.48	1.89	0.49	3.79	0.97	.....	.....
July	1.75	0.45	3.95	0.44	3.98	0.86	.....	.....
August	1.45	0.71	3.10	0.62	4.56	0.76	.....	.....
	4.89	*2.64*	*8.94*	*1.55*	*12.33*	*2.59*	*12.54*	*2.90*
September	7.49	0.57	1.16	0.09	6.50	0.65	.....	.....
October	5.94	0.75	3.55	0.40	2.17	0.88	.....	.....
November	4.44	3.37	2.91	0.82	3.96	1.73	.....	.....
	17.87	*4.69*	*7.62*	*1.31*	*12.63*	*3.26*	*12.13*	*3.14*
Total	47.87	24.90	37.88	19.31	50.26	25.36	48.10	24.65

The run-off as given is stated by A. Fteley, chief engineer of new Croton aqueduct, to have been corrected as far as necessary for the storage, and accordingly represents approximately the natural run-off of the stream.

Evaporation from the Croton River watershed as given by differences between rainfall and run-off in preceding table.

[Inches on watershed.]

Year.	December to May.	June to August.	September to November.	Total.	Year.	December to May.	June to August.	September to November.	Total.
1870	7.55	8.74	8.70	24.99	1885	6.82	12.12	9.11	28.05
1871	8.79	13.03	6.01	27.83	1886	6.73	8.74	8.24	23.71
1872	2.98	10.86	5.70	19.54	1887	6.21	20.73	4.93	31.87
1873	1.39	6.91	8.80	17.10	1888	9.08	8.13	11.33	28.54
1874	*a* 0.50	9.06	6.55	15.11	1889	4.63	8.06	9.94	22.63
1875	0.70	9.48	6.53	16.71	1890	3.52	10.89	8.12	22.53
1876	*a* 0.02	5.38	8.65	14.01	1891	5.60	9.05	6.45	21.10
1877	2.23	10.52	12.37	25.12	1892	9.15	12.26	9.16	30.57
1878	4.69	8.65	9.60	22.94	1893	1.90	9.79	8.61	20.36
1879	3.98	13.92	4.29	22.19	1894	7.54	2.25	13.18	22.97
1880	7.00	8.95	7.33	23.28	1895	4.87	7.39	6.31	18.57
1881	8.53	7.11	7.39	23.03	1896	5.79	9.74	9.37	24.90
1882	12.41	7.68	12.84	32.93	Mean	5.44	9.64	8.38	23.46
1883	5.86	10.32	9.37	25.55					
1884	9.29	10.39	7.51	27.19					

a During this period the run-off exceeded rainfall.

This stream is an exceedingly good water yielder. The minimum yield for a complete water year for the whole period from 1870 to 1896 was in 1883, in which water year, from December to November, inclusive, the total run-off was 16.83 inches.

The Croton watershed contains 31 lakes and ponds, many of which have been utilized as natural storage basins by constructing dams at their outlets. The following tabulation gives the entire natural and artificial storage, either actually carried out or now under construction, in the Croton watershed:

Storage capacity in the Croton watershed.

	U. S. gallons.
Boyds Corners reservoir	2,727,000,000
Middle Branch reservoir	4,004,000,000
Lake Mahopac *a*	575,000,000
Lake Kirk *a*	565,000,000
Lake Glenida *a*	165,000,000
Lake Gilead *a*	380,000,000
Lake Waccabuc *a*	200,000,000
Lake Tonnetta *a*	50,000,000
Barretts Pond *a*	170,000,000
China Pond *a*	105,000,000
White Pond *a*	100,000,000
Pine Pond *a*	75,000,000
Long Pond *a*	60,000,000

a The lakes and ponds marked thus are owned by the city. Those not marked are city reservoirs.

Storage capacity in the Croton watershed—Continued.

	U. S. gallons.
Peach Pond *a*	230,000,000
Cross Pond *a*	110,000,000
Haines Pond *a*	25,000,000
East Branch reservoir	9,028,000,000
Titticus reservoir	7,000,000,000
Caramel reservoir	9,000,000,000
New Croton reservoir	32,000,000,000
Amawalk reservoir	7,000,000,000
Total storage	73,569,000,000

a The lakes and ponds marked thus are owned by the city. Those not marked are city reservoirs.

The drainage area above the new Croton dam now constructing is 360 square miles. It is considered by the Croton aqueduct officials that the storage afforded by this reservoir system will furnish a daily supply of at least 280,000,000 gallons. At this rate the utilization from this drainage area of 360 square miles will become 778,000 gallons per square mile per day, or 1.20 cubic feet per square mile per second.

MAXIMUM AND MINIMUM FLOW OF STREAMS IN NEW YORK.

The data relating to floods in Genesee River, given on pages 72 to 74, as well as the following facts, may be taken as indicating some of the maximum flows of streams in New York.

FLOODS IN CHEMUNG RIVER.

Severe floods have occurred in this stream several times during the historical period, the most severe being the great flood of June, 1889, which caused serious damage to property at Elmira and Corning. Chemung River is formed by the junction of Tioga and Cohocton rivers at Painted Post, a few miles above Corning, the principal tributary of the Tioga in this State being the Canisteo. Tioga River rises near Blossburg, in Tioga County, Pennsylvania, in an elevated region from 1,500 to 2,500 feet above tide. The descent from the extreme head waters near the Fall Brook Coal Company's mines to Blossburg is at the rate of about 22 feet per mile, after which it descends at the rate of about 11 feet to the mile. The streams tributary to the Tioga are also very rapid; they flow mainly through deep, narrow rock valleys, with their heads generally at an elevation of nearly 2,000 feet above tide. Recently the hill slopes have been largely denuded of timber, thus permitting a rapid descent of the rainfall or melted snow. Hence it results that Tioga River not only naturally rises quickly, but its freshet flows have very high velocities. Canisteo River, joining the Tioga from the west, has an average slope of about 5.5 feet per mile. The slope of the Chemung from Painted Post to Elmira is

at the rate of 5.9 feet per mile; thence through the city of Elmira for 3 miles at the rate of 3.5 feet per mile; from Elmira to Chemung, 5.5 feet per mile, and thence to Athens, where it joins the main East Branch of the Susquehanna, 3.4 feet per mile. Cohocton River is also a stream of comparatively low slope.

The foregoing facts indicate that the floods will be slower in rising on Canisteo and Cohocton rivers than on the Tioga. In a general storm, where other conditions are equal, the first flood water to reach Corning and Elmira will come from the Tioga, to be followed later by large flows from the Canisteo and the Cohocton. The areas drained by these streams are approximately as follows:

Areas drained by tributaries of Chemung River.

	Square miles.
Tioga, aside from the Canisteo	750
Canisteo	780
Cohocton	425
Chemung above Elmira	100
Total	2,055

On May 31, 1889, the region tributary to Chemung River above Elmira was visited by a phenomenally heavy rainfall, amounting in many places to nearly 10 inches. The center of this downpour was located about 10 miles south and 15 miles west of Elmira. At Elmira the rainfall was not unusual, 1.5 inches being recorded from 8 p. m. of May 31 to 7 a. m. of June 1; but at Wellsboro, 36 miles southwesterly from Elmira, the total precipitation was 9.8 inches, of which 7.45 inches occurred after 9 p. m. of May 31 and before 7 a. m. of June 1. At South Canisteo, 45 miles westerly from Elmira, a total fall of 6.25 inches was recorded, of which 4.5 inches fell between midnight and 3 a. m. of June 1. Farther up the valley 6 inches were measured between the same hours. At Painted Post a total fall of about 8 inches was reported. At Savonia, on the Cohocton, 5 inches fell, but the fall grew gradually less to the north. At a number of points to the south and southwest rainfalls of from 6 to 8 inches were recorded for May 31, heavy rains occurring as far south as Virginia.

It will be noticed from the preceding statement of the rainfall of May 31 and June 1, 1889, that the heaviest precipitation was practically at the same time over the entire watershed. The following indicates the heights of the flood wave at several points: At Tioga the river was highest about 6.30 a. m. on June 1; Canisteo River was at its highest a little before noon of June 1; at Painted Post the local creeks reached their highest points at 5 a. m., and the Tioga began to rise rapidly about the same time; the Chemung reached a height at this place of 18 feet above low water; at Elmira the river began to rise rapidly about 9 a. m. of June 1 and was at its highest at about 7 p. m.

According to Francis Collingwood,[1] who investigated the Chemung River flood of 1889, for the city of Elmira, the foregoing data indicate that in a flood coming more from the south than from the west the highest water in Chemung River may be looked for about twelve hours after the highest water has passed the Tioga, and at a somewhat later period when the water comes more from the Canisteo and Cohocton rivers. Mr. Collingwood concludes that the flood flow at Elmira will usually be not less than fourteen hours after a heavy rain on the head waters of these streams.

The surveys made by Mr. Collingwood, in which a considerable number of flood elevations were fixed and plotted, show that the discharge of Chemung River at its maximum was about 138,000 cubic feet per second, and the mean velocity 12.72 feet per second. A maximum of 138,000 cubic feet per second, gives 67.1 cubic feet per second per square mile. By the way of comparison, it may be noted that a maximum has been recorded on the Croton watershed of 74.87 cubic feet per second per square mile; also that Genesee River at Mount Morris gave in the flood of 1894 the maximum discharge of 42,000 cubic feet per second, or 48.6 cubic feet per second per square mile.

The Chemung flood of 1889 did considerable damage both at Corning and at Elmira, and the investigations of Mr. Collingwood were with reference to plans for protecting the latter city from devastation by future floods. Several plans were proposed, all including the rectification, clearing, and lowering of the river through the city with such dikes at the side as might be necessary for special protection at exposed points. The estimated cost of these various projects varied from $336,000 to $700,000. So far as known, nothing in the way of constructing the work at Elmira has yet been done.

The city of Corning, which is situated on the banks of Chemung River a few miles above Elmira, was also greatly damaged by the flood of June, 1889. In consequence, it was determined to construct protective works, and an act of the legislature was accordingly passed in 1892, creating a board of river commissioners, with authority to issue bonds for this purpose, under which enactment and amendments thereto bonds to the amount of $150,000 have been issued. The work began in June, 1896, and is now about completed. The plan adopted is to construct earthen dikes to confine the river at all points where it is subject to overflow. The total length of the dikes is about 25,800 feet, or 4.9 miles, and they vary in height from 4 to 19 feet. The river dikes were generally 8 feet wide on top, with a slope of from 3 to 1 (3 horizontal to 1 vertical) on the river side, and a slope of 2 to 1 on the land side.

Whatever the purpose for which an inland stream is to be utilized,

[1] Report on the Prevention of Floods at Elmira.

the first question asked by an experienced engineer is with regard to the minimum flow. If for power development, the minimum flow will determine the amount of power which can be insured on a given head; if for the water supply of a town, the minimum flow will indicate at once the number of people which may be supplied without storage. From every point of view, therefore, a knowledge of the minimum flow is a matter of the first importance. Below are given the minimum flows of the inland streams of the State of New York so far as information is at hand.

LOW-WATER FLOW OF OATKA CREEK.

The drainage area of this stream above the point of measurement is 27.5 square miles. The mean flow for the month of August, 1891, was 6 cubic feet per second; for September, 5.83 cubic feet per second; for October, 5.8 cubic feet per second. Expressed in cubic feet per second per square mile, the foregoing results are 0.218 cubic foot for August, 0.212 cubic foot for September, and 0.211 cubic foot for October. Expressed in inches on the watershed, the run-off of this stream for August to October, 1891, was from 0.24 to 0.25 inch per month. For several days during the months of August to October, 1891, the flow of Oatka Creek was down to about 4.2 cubic feet per second, or to about 0.151 cubic foot per square mile per second. On September 26, 1891, the recorded mean flow for the the day was 3.77 cubic feet per second, or 0.137 cubic foot per square mile per second.

As a general proposition, statements of minimum flows of streams ought not to be based on the record of single days, especially on streams where there are mill ponds above the point of measurement, because such accidental circumstances as the holding back of the water may vitiate the result; from this point of view an average extending over as long a period as possible should be taken.

The measurements of Oatka Creek from August to October, 1891, illustrate well the nearly universal tendency of streams to run either at approximately a fixed rate or to decrease only very slowly after the tributary ground water has become well drawn down. For several days at a time the records show only slight variations.

LOW-WATER FLOW OF GENESEE RIVER.

The drainage area above Mount Morris, the first point of measurement, is 1,070 square miles; above Rochester, the second point, 2,365

A. ERIE CANAL AQUEDUCT AND SOUTH SIDE OF MAIN STREET BRIDGE, ROCHESTER

B. GREAT FLOOD OF 1865 AT ROCHESTER, SHOWING LUMBER LODGED AGAINST AQUEDUCT BRIDGE

square miles. The following table gives the mean monthly flows at Mount Morris and Rochester for several low months of the year 1895:

Mean monthly flow of Genesee River at Mount Morris and Rochester.

Month.	Mount Morris.			Rochester.	
	Mean flow (cubic feet per second).	Cubic feet per second per square mile.	Inches on the water shed.	Mean flow (cubic feet per second.)	Cubic feet per second per square mile.
May	174	0.163	0.19	385	0.380
June	128	0.119	0.13	283	0.226
July	105	0.099	0.11	232	0.165
August	115	0.108	0.12	254	0.169
September	100	0.093	0.10	221	0.106
October	104	0.097	0.11	230	0.093

Comparing the foregoing figures for Mount Morris with those for Rochester for the month of October, 1895, it is seen that the proportion of run-off at Rochester was somewhat less for that month than at Mount Morris, although for the previous months it appears to have been larger. The explanation of this is that there are between Rochester, Mount Morris, and Dansville extensive flats aggregating from 60 to 80 square miles. The temporary ground-water storage of these flats acts to sustain a somewhat more equable flow at Rochester than at Mount Morris, above which point there are proportionately much smaller areas of flats.

The foregoing minimum flows of Genesee River show conclusively that in its present condition it is not a good mill stream. The great variations in run-off are conclusive on this point. The figures show that the run-off of the stream may be exceedingly slack during the summer and fall months.

In the summer of 1846 Daniel Marsh made a series of measurements in order to determine the low-water flow of that year. As the result of 9 measurements made at various times in July and August he placed the minimum flow at Rochester in 1846 at 412 cubic feet per second.

If we examine the meteorological records of western New York for the years 1844 to 1846, we find that the period covered was one of low rainfall. For instance, at Rochester the rainfall for the storage period of the year 1846 (from December, 1845, to May, 1846, inclusive) was only 11.57 inches; the rainfall of the growing period, 11.30 inches; for the replenishing period, 13.16 inches; the total for the water year 1846 being 36.03 inches. For 1845 the total was 34.66 inches. For 1844 the storage period rainfall was 10.52 inches; growing period, 8.23 inches; replenishing period, 7.68 inches; total for the year, 26.43 inches.

At Middlebury Academy, Wyoming County, in the drainage area of Oatka Creek, the rainfall for the water year 1845 was, for the storage period, 12.59 inches; growing period, 4.82 inches; replenishing period, 8.60 inches; total for the year, 26.01 inches. The record for the year 1846 at Middlebury is not given. It is clear, therefore, so far as we have any definite meteorological record, that the measurements made by Mr. Marsh in 1846 were at a time of very low water.

The foregoing statements indicate that apparently the minimum summer flow of Genesee River has decreased from 462 cubic feet per second in 1846 to about 220 cubic feet per second in 1895. As to the reason for this decrease it is believed that the extensive deforestation of the drainage area which has taken place since 1846 offers full explanation. In 1846 the upper Genesee drainage area was still very largely in forest. Probably of the entire area above Rochester the virgin forest was from 65 to 70 per cent of the whole. We have, therefore, apparently a marked case where the deforestation of a large area has materially reduced the minimum run-off.

LOW-WATER FLOW OF HEMLOCK LAKE.

According to a report made by Henry Tracy, the minimum flow of Hemlock Lake (drainage area 43 square miles) is 5 cubic feet per second, or 0.116 cubic foot per square mile per second.[1]

The table on pages 76 and 77 gives, as previously stated, the quantity of water passing out of Hemlock Lake for the period covered and without reference to the natural flow. In order to obtain the approximate natural flow for the year we must take into account the mean elevations of lake surface. Thus, for the water year 1880 the mean elevation of the first month, December, was —1.67, while for the last month, November, it was —1.24. The difference (0.43 foot) represents the gain in depth of storage for the year. Computing for the value of this storage in inches on the drainage basin, we have 0.28 inch, which, added to the quantity of water passing out of the lake (3.07 inches), gives as the approximate total run-off for the year 3.35 inches. Since 1880 was a very dry year, we may compute the flow for the entire water year to be 10.3 cubic feet per second, which again amounts to 0.24 cubic foot per square mile per second. So far as known this is the lowest annual run-off thus far measured in the State of New York.

For the five-year period included in this table, the total rainfall and run-off are as follows:

[1] Report on the cost and policy of constructing reservoirs of Conesus, Hemlock, Honeoye, and Canadice lakes. Senate Document No. 40, 1850.

UPPER FALLS OF GENESEE RIVER AT PORTAGE.

Rainfall and run-off of Hemlock Lake.

Water year.	Rainfall.	Run-off.
	Inches.	*Inches.*
1880	21.99	3.07
1881	24.27	8.38
1882	25.46	14.51
1883	32.24	9.29
1884	26.74	12.57
Add for rise in level		0.40
Total	131.70	48.22

For the five-year period the total run-off was therefore only 36.6 per cent of the rainfall. In 1880 the run-off was only 15.2 per cent of the rainfall.

LOW-WATER FLOW OF MORRIS RUN.

The result of a measurement of Morris Run, a tributary of Oatka Creek, the source of a part of the water supply of the village of Warsaw, Wyoming County, made from July 4 to December 26, 1894, is shown by the accompanying table. The measured drainage area is 156 acres, but it may, by reason of the peculiar topography, be somewhat greater than this. The water issues along the thread of the short valley in the form of springs. The measurement was made by a thin-edged notched weir at a point just below the lowest spring. As may be observed, the flow varied greatly at different times, the minimum being 77,630 gallons per day or 7.2 cubic feet per minute, in October. On July 8 the discharge was 238,580 gallons, or 22.1 cubic feet per minute for twenty-four hours. There is a popular impression that springs do not vary their flow at different seasons. The measurements of Morris Run are valuable, therefore, as illustrating that even a spring-fed stream will gradually decrease during a dry season.

Daily mean discharge in cubic feet per minute of Morris Run near Warsaw, New York, in 1894.

Day.	July.	August.	September.	October.	November.	December.
1		16.0	10.4		10.9	
2		17.3				
3		16.7	8.3			10.0
4	19.4	18.3	8.0	7.8		
5	17.8		7.8	8.2		
6	19.5	16.2			9.4	
7	20.9	14.9		6.7		

Daily mean discharge in cubic feet per minute of Morris Run near Warsaw, New York, in 1894—Continued.

Day.	July.	August.	September.	October.	November.	December.
8	22.1					
9	21.2					
10	21.3					
11	20.8			9.4		21.9
12	20.6			7.8		
13	19.7					16.2
14	20.1					
15	19.7			8.8		14.9
16	19.8		8.8		8.2	
17	18.7		8.2	7.8		
18	18.3		19.0	7.8		13.4
19	17.5			7.2	8.2	
20	17.9					13.6
21	21.2		11.1	7.2	8.2	
22	20.6		8.8		8.8	
23	20.0			7.2		
24	20.4		8.8	53.8	8.2	13.6
25	18.7					
26	17.8			8.8	8.2	13.6
27	17.3			7.8		
28	17.1		8.8			
29	17.8		8.8	7.2		
30	16.3			7.2		
31	16.5	11.7		19.0		

LOW-WATER FLOW OF WEST BRANCH OF CANADAWAY CREEK.

In the summer of 1883 measurements were made of the West Branch of Canadaway Creek in Chautauqua County, from July 18 to September 2 of that year. This stream, which is the source of the water supply of the village of Fredonia, has a drainage area above the point of measurement of 4.3 square miles. The valley is deep cut for a distance of 3 miles from the measuring point to its extreme headwaters. Small springs issue frequently throughout the valley. On July 18, 1883, the stream was flowing at the rate of 541,620 gallons in 24 hours, or 50.2 cubic feet per second, and very gradually decreased to 270,000 gallons, or 25 cubic feet per minute, on July 22. Rains between July 22 and July 29 brought the stream up to a discharge of 1,319,000 gallons per day, or 122.1 cubic feet per minute, on the latter date. The flow then gradually decreased during the month of August until, on August 26, it was only 216,000 gallons per

day, or 20 cubic feet per minute, which was the lowest point reached during the summer of 1883.

This stream can not be considered a good water yielder. A mean discharge of 216,000 gallons in twenty-four hours from a drainage area of 4.3 square miles represents a yield of 0.334 cubic foot per second, or, what is the same thing, 0.078 cubic foot per square mile per second. It is apparent, therefore, that even a spring-fed stream with a deep valley in Chautauqua County may at times furnish a very small outflow, though it should not be overlooked that the flow of 0.078 cubic foot per square mile per second was the extreme minimum for one day only. The relations of this extreme minimum to the daily flows during the period covered by the measurements may be easily gathered from an inspection of the table. The gradual falling in water yield from August 1 to 26 is the most interesting fact revealed by these measurements.

The following was the rainfall at the point of measurements during the month of August, 1883:

	Inches.
August 3	0.04
August 13	0.10
August 20	0.05
August 23	0.05
August 28	1.98

Daily mean discharge in cubic feet per minute of West Branch of Canadaway Creek, near Fredonia, New York.

[Drainage area, 4.3 square miles.]

Day.	July.	August.	September.	Day.	July.	August.	September.
1		56.5	47.6	17		31.7	
2		50.3	45.0	18	50.2	28.4	
3		46.2		19	49.3	29.3	
4		45.4		20	45.7	31.7	
5		39.8		21	44.0	33.2	
6		36.9		22	25.0	22.9	
7		36.0		23		25.6	
8		34.1		24			
9		34.1		25		22.1	
10		33.2		26		20.0	
11		31.7		27		21.3	
12		30.2		28		105.1	
13		30.2		29	122.1	321.9	
14		32.4		30		101.7	
15		27.0		31	62.4	60.0	
16		27.9					

LOW-WATER FLOW OF SKANEATELES LAKE.

So far as can be learned, no definite statements of the minimum flow from this drainage basin, having an area of 73 square miles, have ever been made. Before the taking of the waters of this lake for the supply of the city of Syracuse the supply was ample for the canal, and close estimates were not made. For the run-off of a water year we find by the table on page 78 that 1897 was the lowest thus far measured, the total of that year being 15.61 inches on the watershed. The indications of the table, so far as they go, are that the Skaneateles area is a good water yielder. Nevertheless, it is improbable that 1897 was a year of minimum flow.

LOW-WATER FLOW OF OSWEGO RIVER.

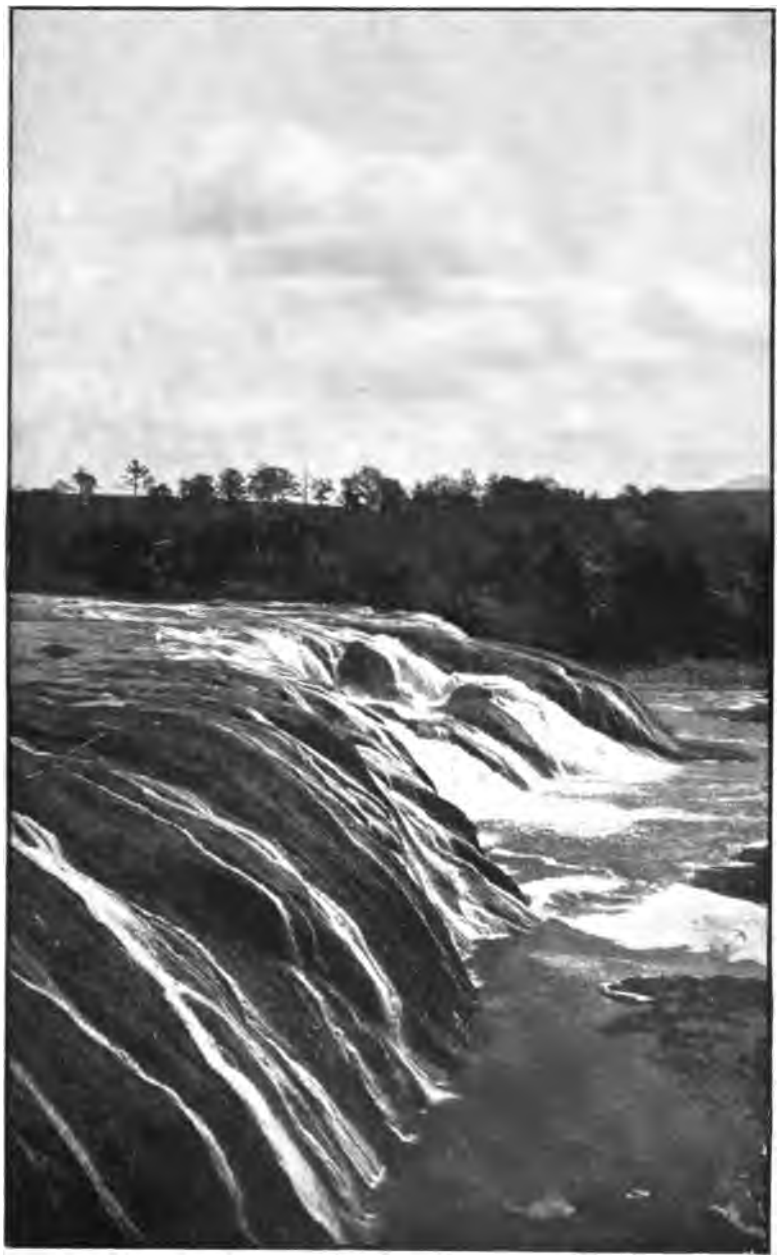
There are no records of any long-continued measurements of the discharge of Oswego River, whose drainage area at the mouth is 5,013 square miles. The minimum flow of this stream has been the subject of judicial inquiry. In August, 1875, in the case of Michael J. Cummings against owners and lessees of the water of the Varick Canal at Oswego, it was decreed:

(1) That the average flow of water from the Oswego River into the Varick Canal in low water in the summer months is about 45,000 to 50,000 cubic feet per minute; (2) that in extreme low water in the summer, and which usually occurs in the month of July or August, it is about 35,000 cubic feet per minute; (3) that the average flow of the whole three summer months is about 75,000 cubic feet per minute.

Varick Canal is entitled to receive one-half the total flow of the river, less the amount of water required for navigation purposes. Hence the average summer flow, according to the decree, is from 90,000 to 100,000 cubic feet per minute (1,500 to 1,670 cubic feet per second). The extreme low-water flow is placed at 70,000 cubic feet per minute for the whole flow of the river, or at 1,170 cubic feet per second, while the average flow of the whole three summer months is given at about 150,000 cubic feet per minute, or 2,500 cubic feet per second. From the foregoing figures we deduce an extreme minimum of perhaps 0.23 of a cubic foot per square mile per second, with an average of low water in the summer months of about 0.30 to 0.33 of a cubic foot per square mile per second.

LOW-WATER FLOW OF BLACK RIVER.

The drainage area of this stream at Watertown is 1,820 square miles. There is very little definite information as to either the maximum or the minimum flow. Aside from a few measurements made by engineers in the employ of the State at the time of construction of Black River Canal and a few made by Frank A. Hines in 1875, there do not appear to be any measurements of flow. As stated in the Report on Water Power of the United States, Tenth Census, probably the minimum flow



HIGH FALLS OF MOHAWK RIVER AT TIME OF LOW WATER.

in an ordinarily dry season may be taken at from 1,000 to 1,100 cubic feet per second for 24 hours. By reasoning from the data of Hudson River, it may be assumed that in very dry years the minimum flow will be less than this. Taking into account the large surface storage on the numerous lakes at the head waters, it is doubtful if Black River in its natural state will, while present forestry conditions are maintained, ever go below about 0.4 of a cubic foot per square mile per second, although it is claimed to have been less than this in 1849. As is shown in detail in another place, there are a large number of reservoirs upon the upper waters of this stream, which, if properly operated, may be expected to keep the low-water flow at a considerably higher figure than 0.4 of a cubic foot per square mile per second, that figure relating to the natural flow of the stream only.

LOW-WATER FLOW OF MOHAWK RIVER.

The drainage area of this stream is 3,400 square miles. According to David H. Van Auken, the engineer of The Cohoes Company, at Cohoes, the minimum flow of Mohawk River does not exceed 800 cubic feet per second, or 0.235 cubic foot per square mile per second. Since considerable water is taken from Mohawk River for the supply of Erie Canal, probably Mr. Van Auken's statement relates to the amount realized for water power at Cohoes, and, in the absence of definite figures as to the amount abstracted for the canal, must be taken as somewhat general. There is, however, a well-defined feeling that the minimum flow of the Mohawk has been gradually decreasing during the last twenty or twenty-five years, due probably to decreasing deforestation of the drainage area.

LOW-WATER FLOW OF HUDSON RIVER.

The drainage area above Mechanicville is 4,500 square miles. Measurements have been made at Mechanicville since October, 1887, the record of which to November, 1896, is presented in the tables on page 82. The natural flow of this stream is somewhat obscured by the presence of a considerable number of lumbermen's reservoirs on its head waters, the total storage of which aggregates about 4,000,000,000 cubic feet. The month of minimum run-off for the whole period covered by the measurements was July, 1888, the mean for the month being 1,537 cubic feet per second, or 0.39 inch on the watershed. For short periods the mean flow has been less than this. Thus, from August 14 to 19, 1890, the mean flow was 1,080 cubic feet per second; also, from October 2 to 6, 1891, inclusive, the mean flow is given at 1,080 cubic feet per second. For 4,500 square miles drainage area this gives 0.24 cubic foot per second. Taking the diversion for the supply of Champlain Canal into account, we have about 0.29 cubic foot per square mile per second as the actually observed minimum flow.

The figures show, moreover, that the minimum of 0.29 of a cubic foot per second has occurred for only two periods, one of six days and the other of five days, a total of eleven days for the whole period covered by the measurements. For July, 1888, the mean flow, including the diversion which was then occurring for the supply of Champlain Canal, may be taken at 0.37 of a cubic foot per square mile per second. For October, 1891, the mean flow for the whole month was 1,472 cubic feet per second, or, including the diversion to the Champlain Canal, 0.36 of a cubic foot per square mile per second. In July, 1890, the mean flow for the month was 1,950 cubic feet per second, and in several other months, as July, 1893, July, 1895, and September and October, 1895, the mean monthly flow varied from about 2,600 to 2,700 cubic feet per second. Hence we may say that for any business where it is not absolutely indispensable to have permanent power, water power on Hudson River may be developed up to the limit of about 0.4 of a cubic foot per square mile per second, with a prospect of not being interrupted on account of low water more than a few days in each year. For electric power, however, or any application of water power requiring a permanent power every day in the year, the development ought not to be based, under present conditions, on more than about 0.24 to 0.25 of a cubic foot per square mile per second, these latter figures relating especially to that portion of the river from which water is diverted for the supply of Champlain Canal. At points above the Glens Falls feeder the indications of the available data are that permanent power developments may be made up to 0.3 of a cubic foot per square mile per second. As is shown in the section on the water power of Hudson River, nearly all of the plants on that stream are developed far beyond these figures.

LOW-WATER FLOW OF CROTON RIVER.

The drainage area above the point of measurement is 338 square miles. The minimum flow of the main Croton River above the point of measurement, as given by J. J. R. Croes, is 0.178 of a cubic foot per square mile per second. The minimum flow of West Branch of Croton River, with a drainage area of 20.4 square miles, is given at 0.02 cubic foot per square mile per second. The lowest mean monthly flow in the period from 1870 to 1896, covered by the table on pages 83 to 85, is for the month of September, 1870, in which month the average daily run-off was 69,401,200 gallons or 9,265,800 cubic feet in 24 hours. These figures give 7.5 cubic feet per second and 0.318 of a cubic foot per square mile per second.

SUMMARY OF KNOWLEDGE OF LOW-WATER FLOW.

Summarizing the present knowledge of the minimum flow of streams in New York, we may say that in western New York for streams like Genesee River, issuing from regions of heavy, compact soil, mostly

deforested, the minimum flows are likely to run as low as 0.1 of a cubic foot per square mile per second, and even less. Spring-fed streams in that region, and those with considerable lake-surface pondage, may be expected to be somewhat greater than this. For the central part of the State the information is too limited to permit of making other than general statements. It is probable, however, that Oswego River, the main stream of the central region, has by reason of its lake pondage and swamp area a minimum flow not much less than 0.3 of a cubic foot per square mile per second. The Mohawk and the upper Hudson may also be placed, while their present condition of forestation is maintained, at a minimum of about 0.3 of a cubic foot per square mile per second. This figure also appears to apply to the Croton drainage area, where there are considerable sand areas, which compensate for the limited forestation. The streams of Long Island issuing from sand plains will give larger yields, the measurements showing a run-off of 0.58 cubic foot per second per square mile drained. The streams of the northern part of the State, which issue from denser forests than the others, may be expected to give minimum yields somewhat in excess of 0.3 of a cubic foot per square mile per second. Little is known as to the yield of streams tributary to the Allegheny, Susquehanna, and Delaware rivers aside from the measurements of Eaton and Madison brooks by Mr. Jervis, in 1835. Apparently no measurements of any other of these streams have been made. It is probable, however, that many of them are not specially different in water-yielding capacity from the Neshaminy, Tohickon, and Perkiomen creeks in Pennsylvania.[1]

In view of the vast importance of a detailed knowledge of stream flow in the State of New York, on account not only of the canal interests of the last seventy-five years, but also on account of the great possibilities of water-power developments, it is a matter of surprise that more extended measurements of the inland streams have not been made.

[1] For details of the measurements of the Neshaminy, Tohickon, and Perkiomen creeks, see a paper, Observations on rainfall and stream flow in eastern Pennsylvania, by John E. Codman. Proc. Eng. Club of Philadelphia, Vol. XIV (July to September, 1897).

[For index, see Part II of this report—Water-Supply Paper No. 25.]

DEPARTMENT OF THE INTERIOR

WATER-SUPPLY

AND

IRRIGATION PAPERS

OF THE

UNITED STATES GEOLOGICAL SURVEY

No. 25

WASHINGTON
GOVERNMENT PRINTING OFFICE
1899

UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

WATER RESOURCES

OF THE

STATE OF NEW YORK

PART II

BY

GEORGE W. RAFTER

WASHINGTON
GOVERNMENT PRINTING OFFICE
1899

CONTENTS.

	Page.
Letter of transmittal	107
Water-storage projects	109
Genesee River storage reservoir	109
Preliminary investigations	110
Interests to be served	111
Investigation of the flood of 1865	112
Mount Morris sites	113
Portage site	114
Comparison of Mount Morris and Portage sites	122
Summary	124
Water storage on Hudson River	125
Early surveys	125
Recent investigations	127
Reservoir sites on Sacundaga, main Hudson, and Schroon rivers	128
Effect of proposed storage on river flow	132
Summary	134
Development of water powers	135
Power development at Niagara Falls	135
Niagara Falls Hydraulic Power and Manufacturing Company	136
Niagara Falls Power Company	138
Power plant at Massena, on St. Lawrence River	143
Inland waterways	144
Trade and commerce of Hudson River	144
State canals	145
Early history	145
Growth and decline of canal transportation	151
Cost and revenues of the New York State canal system	154
Improvement of Erie Canal	155
Description of the canals now in operation, and their water supply	157
Eastern division of Erie Canal	158
Water supply of the eastern division	158
Middle division	161
Reservoirs of the middle division	164
Western division	165
Ship-canal projects and water supply	166
Loss of water from artificial channels	173
Use and value of water power	178
Water power of Erie Canal	178
Power at Black Rock	178
Power at Lockport	179
Power at Medina	182
Selling price of water power	184
State ownership of inland waters	186
Future use of water power in New York	188
Obstructive effect of frazil or anchor ice	190
Water yield of sand areas of Long Island	191
Index	199

ILLUSTRATIONS.

		Page.
PLATE I.	Upper fall of Genesee River at Rochester, New York, at time of flood	112
II.	East side of Genesee Gorge at site of proposed Portage dam	114
III.	*A*, Lumberman's dam on Cedar River; *B*, Lumberman's dam on Indian River	126
IV.	*A*, The George West Paper Mill on Hudson River at Hadley, New York; *B*, Hudson River Pulp and Paper Company's mills at Palmer Falls on Hudson River, New York	132
V.	*A*, Glens Falls Paper Mill at Fort Edward, New York; *B*, Dam of the Hudson River Power Transmission Company during construction	134
VI.	Power house of the Niagara Falls Hydraulic Power and Manufacturing Company	136
VII.	Penstock of the Niagara Falls Hydraulic Power and Manufacturing Company	138
VIII.	*A*, Power house of Niagara Falls Power Company; *B*, Outlet of tunnel of Niagara Falls Power Company	140
IX.	*A*, Erie Canal at Buffalo, New York; *B*, Black Rock guard lock on Erie Canal	148
X.	Effect of decrease of business on Erie Canal	152
XI.	Erie Canal at Little Falls, New York	158
XII.	Erie Canal at Syracuse, New York	162
FIG. 1.	Map of drainage area of Hudson River above Glens Falls	126
2.	General plan of development of the Niagara Falls Hydraulic Power and Manufacturing Company	137
3.	Map of Niagara Falls and vicinity showing location of the great tunnel	139

LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF HYDROGRAPHY,
Washington, November 26, 1898.

SIR: I have the honor to transmit herewith a manuscript on the Water Resources of the State of New York, prepared by Mr. George W. Rafter, and to recommend that it be published as one of the series of papers on Water Supply and Irrigation.

This manuscript is a continuation of the material printed in Water-Supply Paper No. 24, which related mainly to the physical conditions of river systems of the State of New York, and particularly to the available water supply, the floods, and the low water of some of the typical streams. In the present paper a discussion is given of water-storage projects and of the development of water power and waterways. The paper as originally presented was intended for publication as a whole in one of the annual reports. This was found impracticable, and to secure publication at an early date it has been necessary to subdivide the manuscript to conform with the limitations imposed regarding the size of papers in this series. In spite of this disadvantage it is believed that the information contained in these two papers (Nos. 24 and 25) will be of value not only to the people of New York, but to those of other States.

Very respectfully,

F. H. NEWELL,
Hydrographer in Charge.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

WATER RESOURCES OF THE STATE OF NEW YORK, PART II.

By GEORGE W. RAFTER.

WATER-STORAGE PROJECTS.

Among the projects for storing water for power and other purposes are two of special importance with which the author has been concerned; the first of these is on Genesee River and the second on Hudson River. The following statements are for the most part condensed from more detailed reports in the Annual Report of the State Engineer and Surveyor for 1896.

GENESEE RIVER STORAGE RESERVOIR.

A general description of this river has been given in Part I (Water-Supply Paper No. 24), on page 25; its discharge measurements have been discussed on page 70, and reference has been made on page 90 to the low-water flow, indicating that during the summer the available supply is small. In spite of this fact, development of water power has proceeded rapidly. As shown by the reports on the Water Power of the United States in the Tenth Census (1880), the total water power on Genesee River from Rochester to Portage in 1882 was 6,882 net horsepower. An examination of the amount in use on the same reach of river in 1896 showed that the total, based on manufacturers' rating of wheels, was 19,178 net horsepower, or based on the manufacturers' statements of the quantity of water required to operate the wheels, and allowing 75 per cent efficiency of the water, the total power developed by the wheels in place in 1896 is found to be 17,248 net horsepower, or about three times that in 1882. In comparison with the figures it should be noted that for several months during the summer and fall of 1895 the total power did not exceed 6,000 horsepower. The same condition has existed during the dry period of a number of years previous, but not so seriously as in the fall of 1895.

PRELIMINARY INVESTIGATIONS.

The increased demand for power, as well as the serious summer droughts, led to the formulation of a project for constructing a storage reservoir at some point on the head waters of Genesee River for assisting the summer flow. The first project included the development of the basin of Honeoye Lake to its full capacity, surveys having been made for that purpose in 1887 and 1888. It appeared, however, that the yield of this drainage basin, which is only about 43.5 square miles, was hardly adequate for the results desired, the estimate showing that even when developed to its full capacity it could not be depended on to furnish, in a dry year, more than 75 cubic feet per second, while the exigencies of the case demanded at least several hundred cubic feet per second. The project of building a large storage reservoir on upper Genesee River was then formulated by the Rochester Chamber of Commerce.

In the meantime a number of breaks on the long level of the Erie Canal, which extends from the foot of the locks at Lockport to the eastern part of the city of Rochester, a distance of about 62.5 miles, had emphasized the importance of the State's providing additional water for feeding the canal east of Rochester. For this purpose the construction of a large storage reservoir was advocated by the Rochester Chamber of Commerce as a State work, with the result that under a resolution of the senate dated March 21, 1889, the State engineer and surveyor was directed to make a general investigation in regard to the possibility of storing water on the upper Genesee. The report made under the authority of this resolution appears in the Annual Report of the State Engineer and Surveyor for the year 1890. In 1892, under authority of a concurrent resolution dated March 15 of that year, Governor Flower appointed a commission consisting of Evan Thomas, Judge Charles McLouth, and John Bogart to investigate and report on the whole question of storage on the upper Genesee. This commission examined the site of the proposed reservoir and reported that it was entirely feasible to construct a large reservoir on the upper Genesee River, the site especially considered by the commission being in the Genesee canyon or gorge, a short distance above Mount Morris, already described in Part I.

As the result of the recommendations of this commission, the sum of $10,000 was appropriated at the legislative session of 1893 for the purpose of studying in detail the several proposed sites for dams in the canyon of Genesee River, above Mount Morris. At that time the work was placed in charge of the author, and has since remained in his hands.[1]

At the legislative session of 1894 a bill to construct a dam in the canyon a short distance above Mount Morris passed the senate, but

[1] The result of the studies in 1893 may be found in the Annual Reports of the State Engineer and Surveyor for the fiscal years ending September 30, 1893 and 1894.

failed in the assembly. At the session of 1895 a similar bill passed both the senate and assembly, but was vetoed by Governor Morton, largely on the ground that the bill as passed made no provision for the owners of the water power and other interested parties bearing any portion of the expense. In his veto Governor Morton expressed the belief that if the State should determine to build a dam on Genesee River some provision should be made by which the city of Rochester—and possibly other localities interested in the work—might contribute to the expense of construction. Governor Morton also pointed out that if the proposed canal enlargement be approved by the people public sentiment might justify the construction of a storage dam on Genesee River for canal purposes. On the other hand, if the proposition to deepen the canal should not be approved the question would still remain whether such a dam might not be desirable for the purpose of regulating the river and increasing the water power thereon.

In order to complete the preliminary investigations relative to the proposed Genesee storage, Governor Morton, in 1896, approved an additional appropriation, which was expended during the summer of that year in completing the additional surveys. To the present time the State has expended on preliminary investigation of the Genesee storage project the following amounts: In 1890, $3,000; in 1892, $7,000; in 1893, $10,000; in 1896, $10,000; in all, $30,000. As a result of this expenditure complete plans and specifications have been prepared as shown in the Annual Report of the State Engineer and Surveyor for 1896.[1]

INTERESTS TO BE SERVED.

The following are the interests to be served by the construction of these extensive storage works on Genesee River:

(1) The flow of the river would be regulated, thus effectually preventing in the future the devastating floods which occurred in 1815, 1835, 1857, 1865, 1889, 1893, 1894, and 1896. The floods in the years just

[1] By way of presenting a full list of the work on the Genesee storage, reference may be made to the special report of John Bogart, State engineer and surveyor, in Appendix F of the Annual Report of the State Engineer and Surveyor for the fiscal year ending September 30, 1890. The reports of Messrs. Bailey and Kibbe, assistant engineers to Mr. Bogart, are covered by the same reference. The report of Martin Schenck, State engineer and surveyor, may be found at page 44 of the Annual Report of the State Engineer and Surveyor for the fiscal year ending September 30, 1893. The report of E. Sweet, ex-State engineer and surveyor, as consulting engineer, may be found in Appendix H of the Annual Report of the State Engineer and Surveyor for the fiscal year ending September 30, 1893. The report of the commissioners appointed in 1892 by Governor Flower may be found in Senate Doc. No. 23, 1893. The first report of the writer may be found in Appendix G of the Annual Report of the State Engineer and Surveyor for the fiscal year ending September 30, 1893. The second report may be found in Appendix E of the Annual Report of the State Engineer and Surveyor for the fiscal year ending September 30, 1894. The work done in 1896 is described at length in the Annual Report of the State Engineer and Surveyor for the fiscal year ending September 30, 1896. See also a paper by the writer, The Genesee River storage and its relations to the Erie Canal and the manufacturing interests of western New York, prepared for the Rochester Chamber of Commerce. This paper contains a large amount of historical information not given in the official reports. Governor Morton's veto may be found in the Governor's State Papers for 1895.

enumerated were especially severe, but floods not so severe, yet doing considerable damage, have occurred in several of the intervening years. The most severe flood was that of 1865, which destroyed fully $1,000,000 worth of property in the city of Rochester.

(2) Water would be supplied for the enlarged Erie Canal. According to Mr. Bogart's report of 1890, there should have been provided a storage on Genesee River of 1,500,000,000 cubic feet for the purpose of supplying Erie Canal as it existed at that date. Estimates made in 1896 show that for the purpose of fully supplying the enlarged canal, as now in process, there should be made a storage on Genesee River of 2,500,000,000 cubic feet.

(3) The agricultural production of the broad level area included in Genesee Valley between Rochester, Mount Morris, and Dansville, estimated at from 60 to 80 square miles, might be greatly increased by moderate irrigation if the flood contingency was removed and the proper irrigation channels were constructed.

(4) Considerable sanitary benefit to this section would result from the increased flow during the low-water period through the proposed regulation. The entire sewage at Rochester, a city of 160,000 inhabitants, now passes into Genesee River. The channel of this stream, between the foot of Lower Falls at Rochester and Lake Ontario, is so broad and deep that during the time of extreme low water in the summer and fall the current is scarcely perceptible. The sewage of the city therefore lodges in this section, producing a serious nuisance. The regulation of the river, by preventing floods, would also improve the sanitary condition of the broad upper valley, where the annual overflow has been shown to cause more or less sickness.

(5) The water power would be increased. Wheels are now set on Genesee River capable of producing, at the manufacturers' rating, 19,178 horsepower, while the low-water flow of the stream does not exceed about 6,000 horsepower. The regulation as finally proposed would produce much more power than this.

In summation of the preceding points it may be urged, in general, that in constructing the proposed Genesee storage dam, in addition to the private interests to be conserved, public service of an extended character would be performed.

INVESTIGATION OF THE FLOOD OF 1865.

The great flood of March, 1865, worked such destruction that the legislature, on May 1 of that year, passed an act appointing commissioners to ascertain the cause of the inundation of the city of Rochester, what obstructions, if any, had been placed in the river, and what measures, proceedings, and remedies were necessary to guard against the recurrence of such an inundation. The commissioners appointed under this act examined carefully the evidence as to the flood, and arrived at the conclusion that there were three principal causes:

UPPER FALL OF GENESEE RIVER AT ROCHESTER, NEW YORK, AT TIME OF FLOOD

(1) The sudden melting of an immense body of snow which had accumulated during the previous winter.

(2) Obstructions caused by the bridge and embankment of what is now the New York, Lake Erie and Western Railway at Avon. The openings at this place are stated to have been adequate for ordinary floods, but entirely too small for the quantity flowing in March, 1865. Hence, at the time of greatest flow, the water stood three feet higher on the upper side of the embankment than on the lower side. The embankment finally gave way, thus allowing a large quantity of ponded water to flow suddenly down the river, filling the channel at Rochester beyond its carrying capacity.

(3) Obstruction of the channel of the river through the city of Rochester in such manner as to cause overflows into the Erie and Genesee Valley canals at that place. The commissioners also point out that the construction of the Erie Canal aqueduct is such as materially to increase the obstruction at Rochester.

From the best available figures the maximum flow at Rochester in the great flood of March, 1865, probably did not exceed about 40,000 cubic feet per second. The danger limit is reached when the flow at that place approximates 33,000 cubic feet per second.

The following are the openings of the several bridges, etc., spanning Erie Canal in the city of Rochester, as they exist at present: Court street bridge, 5,081 square feet; Main street, 3,367 square feet; Andrews street, 4,511 square feet; Central avenue, 4,450 square feet; Erie Canal aqueduct, 4,308 square feet.

As a chief cause of the 1865 flood the commissioners considered that cutting off the forests and clearing lands were likely to lead to heavier floods from year to year. In view, therefore, of what seemed to the commissioners a constant source of danger, they arrived at the conclusion that a much larger waterway through the city of Rochester was imperative. It may be here remarked that the waterway at Rochester is still substantially the same as in 1865; if anything, it has been somewhat contracted by various constructions since that date.[1]

MOUNT MORRIS SITES.

Referring to Mr. Bogart's report of 1890, it is learned that the investigations of that year were general in their character. The work was carried on more particularly with reference to a location in Genesee River gorge, between Mount Morris and the foot of the Portage Falls. No detailed surveys were made further than necessary to make a general estimate of the cost of a dam 58 feet in height, which would store 1,500,000,000 cubic feet, the amount considered necessary for canal purposes alone. Such a dam, Mr. Bogart estimates, could be erected for about $1,000,000.

[1] For report of the commissioners appointed to investigate the causes of the inundation of the city of Rochester in March, 1865, see Ass. Doc. No. 117 (1866).

The work performed under the direction of the author, in 1893, was of an entirely different character. The report of 1890 having indicated the Mount Morris Canyon as a desirable location, with a number of sites pointed out, of which general investigations had been made, it became desirable to investigate those sites in detail and to prepare close estimates of the cost of constructing dams at each. Detailed investigations were accordingly made of the three sites favorably reported upon in 1890, the results of which may be found in the Annual Reports of the State Engineer and Surveyor for 1893 and 1894, where estimates of the cost of the several dams are also given in detail. Referring to the estimates, it appears that at site No. 1, in Mount Morris Canyon, a dam raising the water surface 130 feet would cost, if built of concrete alone, $2,450,000, but if built with sandstone faces throughout, except for the spillway, where granite is provided, the estimated cost would become $2,590,000. A dam of the same height at site No. 2, if built throughout of concrete, would cost $2,600,000, but with sandstone faces and independent spillway the cost would be $2,720,500, or, with roadway, $2,785,000.

In regard to the total storage to be obtained in Mount Morris Canyon the following are the figures at sites Nos. 1 and 2, the two sites chiefly considered: At site No. 1 a dam 130 feet in height will store 7,700,000,000 cubic feet, and at site No. 2 a dam of the same height will store 7,040,000,000 cubic feet. Since no conclusion has been reached as to which of these sites to adopt, for the purposes of comparison a mean of 7,370,000,000 cubic feet has been taken as the approximate available storage, and the mean of $2,785,000 as the approximate total cost. On this basis the estimated cost of this storage becomes $377.88 per million cubic feet stored.

PORTAGE SITE.

As already stated, the investigations of the Genesee River storage project were finally completed in 1896. In that year detailed surveys were made of a new site known as Portage site (shown on Pl. II), the proposed dam to be located at Portage, about 1,400 feet above the Erie Railway bridge, at a point where the gorge presents extremely favorable conditions for the erection of a high dam. At this place solid rock exists immediately in the bed of the river, with only a couple of feet of water flowing over it, and also extends high up on the bluffs at either side, whereas at all of the sites in the gorge near Mount Morris the rock was only found at from 15 to 20 feet below the water surface and of such an open texture as to require cut-off trenches about 30 feet deep, or to a total depth of nearly 50 feet below the water. The proposed Portage dam is also 500 feet vertically above the previously mentioned dam site, thus rendering that additional number of feet available for power purposes—a fact which

EAST SIDE OF GENESEE GORGE AT SITE OF PROPOSED PORTAGE DAM

places a materially different aspect on the commercial side of the Genesee River storage project.

A short distance above the proposed Portage site the upper Genesee Valley broadens out to a width in places of from one to two miles, although the general width of the valley does not exceed, for several miles in extent longitudinally, about one mile. It narrows in two or three places to a less width than this. The valley is now a good agricultural region, in a fair state of cultivation, and presents, on the whole, as favorable conditions for farming as any similar valley in the State. The Western New York and Pennsylvania Railway passes through the middle of the valley on the line of the abandoned Genesee Valley Canal. Along the line of this railway the villages of Portageville, Rossburg, Wiscoy, and Fillmore are situated. The reservoir project includes the relaying of the railway above the flow line on the west side of the valley, as well as the removal of the villages named. The total area below the flow line is 12.4 square miles and the entire area proposed to be taken for reservoir purposes, including a strip 10 feet vertically above the flow line, is 13.7 square miles. The project also includes the removal of several cemeteries, the building of highway bridges across the reservoir, and the construction of a roadway entirely around the same.

Without having made a detailed canvass, it is estimated that the present population of the proposed Portage reservoir site, in the villages and on the farms, is about 1,200. In reference to dispossessing this number of people of their homes for the purpose of creating a large storage reservoir, it may be said that such a proceeding is not only not uncommon in this State, but that the population to be removed in the case of the new Croton reservoir is far greater than at the Portage reservoir. According to maps furnished by the Croton water department, it appears that the new Croton reservoir includes the taking of either the whole or parts of something like three large villages and nine or ten hamlets. The total population to be removed from the submerged area of the new Croton reservoir is not given, but actual inspection of maps of the proposed sites indicates that it must be several times larger than the number to be dispossessed at Portage. The villages of Katonah, Purdy Station, and Croton Falls are much larger than any of the villages in the Portage reservoir site. The main line of the New York and Northern Railroad passes for several miles through the valley and requires relocating above the flow line, the same as is proposed for the Western New York and Pennsylvania Railway along the Portage reservoir. It appears, therefore, that the city of New York is now doing under State laws everything in the way of so-called radical change which it is proposed to do at Portage. In both cases the sufficient reason for these changes may be found in the better meeting of public necessities.

The estimated cost of the proposed Portage reservoir, including land damages, dam, reconstruction of railway, removal of cemeteries, the cutting of all timber within the drainage areas, the construction of highway bridges, etc., is $2,600,000, the storage to be provided by this expenditure amounting to 15,000,000,000 cubic feet; at this rate the cost per million cubic feet stored is $173.33. The main characteristics of the proposed reservoir are shown by the following table, condensed from pages 708 and 709 of the report of the State Engineer and Surveyor of New York for 1896:

Capacity of proposed Portage reservoir.

Elevation of water surface above sea level.	Area of water surface.	Total volume of water in reservoir.	Inches on watershed.
Feet.	*Sq. miles.*	*Cubic feet.*	
1,100.0	0.2820	101,400,000	0.044
1,105.0	0.5330	317,623,000	0.094
1,110.0	0.8340	838,900,000	0.143
1,115.0	1.1350	450,100,000	0.194
1,120.0	1.4357	566,300,000	0.244
1,125.0	2.0659	942,100,000	0.406
1,130.0	2.6692	1,318,000,000	0.567
1,135.0	3.3264	1,694,000,000	0.729
1,140.0	3.9566	2,070,000,000	0.891
1,145.0	4.5255	2,780,000,000	1.196
1,150.0	5.0944	3,490,000,000	1.502
1,155.0	5.6633	4,200,000,000	1.808
1,160.0	6.2322	4,910,000,000	2.113
1,165.0	6.8293	5,945,000,000	2.559
1,170.0	7.4264	6,980,000,000	3.004
1,172.0	7.6652	7,395,000,000	3.182
1,173.0	7.7846	7,602,000,000	3.271
1,175.0	8.0235	8,016,000,000	3.451
1,180.0	8.6206	9,051,000,000	3.896
1,185.0	9.4362	10,366,000,000	4.462
1,190.0	10.2518	11,681,500,000	5.016
1,195.0	11.3007	13,257,000,000	5,710
1,200.0	12,3495	15,000,000,000	6.458

Comparing the foregoing statements of cost with those made on the preceding page with reference to the cost of the proposed reservoir in Mount Morris Canyon, it appears that at Portage a storage of 15,000,000,000 cubic feet can be made for somewhat less than the cost

of 7,300,000,000 cubic feet at Mount Morris; or, as a general statement, we may say that a given expenditure at Portage produces double the storage that it will produce at Mount Morris. The Portage reservoir develops the full capacity of the drainage area for such a dry year as 1895. It is considered that this full development is necessary in order to obtain the most satisfactory results in river regulation.

As reasons in detail for preferring Portage site to that at Mount Morris, the following may be mentioned:

(1) The Portage site affords more water for a given expenditure.

(2) The Portage site is considered safer than the Mount Morris site. As shown in the Genesee Storage Reports of 1893–94, the shales at Mount Morris are open; and while it is, without doubt, possible to make a safe dam there, it would be at much greater cost than at Portage. In view of the large storage provided at either place, the dam must be absolutely safe, as its failure would work vast destruction.

(3) The material for the dam is nearly all on the ground at Portage, while at Mount Morris it needs to be brought from a distance.

(4) The Portage site affords greater water-power development. With the Genesee storage dam located at Mount Morris the total head on which the storage can be applied is 282 feet, while with a dam at Portage the total head on which the stored water may be applied is 782 feet.

(5) On account of great depth of foundation at Mount Morris, it would be necessary to expend over $1,000,000 before the dam could be brought to the level of the present water surface. The conditions are such that the floods of every spring would sweep over the work, obliterating all evidence that any money had been expended, which must necessarily continue for at least two or three years, until the foundations could be fully placed. At Portage, on the other hand, a good foundation is found near the water level. Indeed, the difference in cost of foundation is such that nearly the total expenditure at Mount Morris is for the dam, the flowage ground costing only $75,000, while at Portage the estimated cost of the dam is only $1,000,000, the balance of the expenditure there being for right of way, change of railway line, etc.

The proposed regulation of Genesee River has been computed on the basis of a minimum discharge of 300 cubic feet per second, in the case of a reservoir storing 7,500,000,000 cubic feet, and also on a basis of 457 cubic feet per second in the case of a reservoir storing 15,000,000,000 cubic feet. As to the reason for fixing upon these minimums, it may be remarked that in river regulation the outflow from the storage reservoir should be so arranged as to make the benefit to all parts of the stream equal. Especially is this proposition true when, as in the present case, there is water power distributed

throughout the whole extent of the stream below the storage point. Obviously the way to do this is to plan for an outflow proportional to the drainage area. In the present case we have a drainage area at Rochester of 2,365 square miles, and one of 1,000 square miles above Portage, or the area above Rochester is about 2⅜ times the area above Portage. The minimum regulated flow at Rochester may justly be made 2.365 times the assumed minimum flow at Portage.

Assuming 680 cubic feet per second as the flow below which the stream will never be allowed to fall at Rochester, we have for a reservoir storing 7,500,000,000 cubic feet a corresponding minimum outflow from the reservoir of 300 cubic feet per second, or for a storage of 15,000,000,000 cubic feet an outflow of 457 cubic feet per second, the latter figure being arrived at by assuming the maintenance of a minimum flow at Rochester of at least 1,080 cubic feet per second. The computations of the tables on pages 119 to 121 are carried out on this basis. The regulated flows for the month of May are greater than for the other months. They are also greatest during the months of canal navigation, the addition being made in order to provide for the quantity of water to be taken for the enlarged Erie Canal, which quantity has been fixed at 80 cubic feet per second for every month of the navigation season except May, and at 177 cubic feet per second for that month, the excess quantity for the month of May being required in order to provide for filling the canal at the beginning of the month.

The first table shows the effect on the flow of Genesee River from June, 1894, to November, 1896, inclusive, as influenced by the storage at Portage of 7,500,000,000 cubic feet of water, provided at least 300 cubic feet per second is allowed to flow continually at Portage, and at least 600 cubic feet per second is always flowing at Rochester in addition to the amount required for canal purposes. The figures given in the left-hand column show the proposed minimum flow at Rochester, this being the 600 second-feet above noted, together with 80 second-feet for the canal for the months from June to November, inclusive, and 177 second-feet for the month of May. The next two columns give the discharges at Rochester and Portage under natural conditions. The fourth column is the difference between these, or the quantity of water entering the river below Portage, and next to this is the minimum amount to be added at Portage in order to maintain the proposed minimum flow at Rochester of 600 cubic feet per second, not including the amount taken by the canal. The quantity available at Rochester for power purposes is shown in the next column, and is obtained by adding the flow at Rochester, less the flow at Portage, to the actual flow from Portage reservoir and the surplus flowing over the spillway at Portage reservoir, and then deducting the quantity taken by the canal.

Regulation of Genesee River by storage at Portage.

[With storage of 7,500,000,000 cubic feet at Portage and flow of at least 600 second-feet at Rochester.]

Month.	Proposed minimum flow at Rochester.	Natural flow at Rochester.	Natural flow at Portage.	Flow at Rochester less flow at Portage.	Minimum amount to be added at Portage.	Available at Rochester.	Actual flow from Portage reservoir.	Surplus flowing over spillway.
1894.	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*	*Sec.-feet.*
June	680	2,321	981	1,340	.....	2,205	300	645
July	680	292	123	169	511	600	511	.....
August	680	442	187	255	425	600	425	.....
September	680	1,963	830	1,133	.....	1,353	300	.....
October	680	899	380	519	161	739	300	.....
November	680	1,729	731	998	.....	1,505	300	287
December	600	1,256	531	725	.....	1,241	300	216
1895.								
January	600	1,335	565	770	.....	1,330	300	260
February	600	495	209	286	314	600	314	.....
March	600	3,985	1,684	2,301	.....	3,867	300	1,266
April	600	4,257	1,800	2,457	.....	4,197	300	1,440
May	777	385	163	222	555	600	555	.....
June	680	283	120	163	517	600	517	.....
July	680	232	98	134	546	600	546	.....
August	680	254	108	146	534	600	534	.....
September	680	221	93	128	552	600	552	.....
October	680	230	97	133	547	600	547	.....
November	680	993	420	573	107	793	300	.....
December	600	2,710	1,146	1,564	.....	1,864	300	.....
1896.								
January	600	964	408	556	44	856	300	.....
February	600	2,005	848	1,157	.....	1,457	300	.....
March	600	6,158	2,604	3,554	.....	4,999	300	1,145
April	600	7,172	3,033	4,139	.....	7,155	300	2,716
May	777	347	147	200	577	600	577	.....
June	680	654	277	377	303	600	303	.....
July	680	501	211	290	390	600	390	.....
August	680	416	176	240	440	600	440	.....
September	680	327	138	189	491	600	491	.....
October	680	3,667	1,556	2,111	.....	2,331	300	.....
November	680	1,728	731	997	.....	1,486	300	269

The actual flow from Portage reservoir is taken to be the minimum of 300 cubic feet per second ordinarily assumed, plus the amount necessary to make up the deficiency in the quantity of water entering the river at points between Portage and Rochester. The last column that on the right-hand side, shows the surplus flowing over the spillway at Portage reservoir during the comparatively few months when the natural flow has filled the reservoir, supplied all demands of evaporation from the surface, and still is in excess.

The next table exhibits the condition of the reservoir from month to month under the above conditions. The figures are given not in cubic contents but in equivalent depth in inches on the total tributary watershed of 1,000 square miles. The reservoir is assumed to be full at the beginning and end of June, 1894, the total storage of the reservoir being equivalent to 3.23 inches in depth on the watershed. The total waste from June 1, 1894, to December 1, 1896, equals, under the conditions of this table, 9.36 inches on the watershed.

Flow into and from Portage reservoir under the conditions assumed.

[In inches on watershed.]

Month.	Inflow to reservoir.	Outgo from reservoir.			Excess.	Deficiency.	In reservoir at end of month.	Wasted.
		Evaporation.	Amount to stream.	Total outgo.				
1894.								
June	1.10	0.03	0.33	0.36			3.72	0.72
July	.14	.04	.59	.63		0.49	2.76	
August	.22	.04	.49	.53		.31	2.45	
September	.93	.03	.33	.36	0.57		3.02	
October	.44	.02	.35	.37	.07		3.09	
November	.82	.01	.33	.34	.48		3.25	.32
December	.61	.01	.35	.36	.25		3.25	.25
1895.								
January	.66	.01	.35	.36	.30		3.25	.30
February	.22	.01	.33	.34		.12	3.13	
March	1.94	.01	.35	.36	1.58		3.25	1.46
April	2.01	.02	.33	.35	1.66		3.25	1.66
May	.19	.04	.64	.68		.49	2.76	
June	.13	.04	.58	.62		.49	2.27	
July	.11	.03	.63	.66		.55	1.72	
August	.12	.03	.61	.64		.52	1.20	
September	.10	.02	.62	.64		.54	.66	
October	.11	.01	.61	.62		.51	.15	
November	.47	.01	.33	.34	.13		.28	
December	1.32	.01	.35	.36	.96		1.24	

Flow into and from Portage reservoir under the conditions assumed—Cont'd.

[In inches on watershed.]

Month.	Inflow to reservoir.	Outgo from reservoir.			Excess.	Deficiency.	In reservoir at end of month.	Wasted.
		Evaporation.	Amount to stream.	Total outgo.				
1896.								
January	.47	.01	.35	.36	.11	.....	1.35	.....
February	.91	.01	.32	.33	.58	.....	1.93	.....
March	3.00	.01	.35	.36	2.64	.....	3.25	1.32
April	3.38	.02	.33	.35	3.03	.....	3.25	3.03
May	.17	.03	.67	.70	.....	.53	2.72	.....
June	.39	.04	.34	.38	.01	.....	2.73	.....
July	.24	.04	.45	.49	.....	.25	2.48	.....
August	.20	.04	.51	.55	.....	.35	2.13	.....
September	.16	.02	.57	.59	.....	.43	1.70	.....
October	1.74	.02	.35	.37	1.37	.....	3.07	.....
November	.82	.01	.33	.34	.48	.....	3.25	.30

Similar tables might be given, showing the regulation of the river as affected by the storage at Portage of 15,000,000,000 cubic feet of water for the same period, with at least 457 cubic feet per second always flowing at Portage, and at least 1,000 cubic feet per second at Rochester, in addition to the amount required for the canal. The chief difference is that during only three months of this period would there be any overflow through the spillway, the total waste equaling 2.11 inches. This would be in June, 1894, 521 second-feet; in April, 1895, 1,058 second-feet; in April, 1896, 350 second-feet. The amount at Rochester under the same conditions would be in no case below 1,000 second-feet.

It may here be pointed out that had the enlarged canal been in operation in July, 1894, and taking the estimated quantity of 80 cubic feet of water per second from Genesee River, the amount of water going to the canal would have been 27.4 per cent of the total flow of the river for that month; in August 18.1 per cent; in May, 1895, 46 per cent; in June, 28.3 per cent; in July, 34.5 per cent; in August, 31.5 per cent; in September, 36.2 per cent; and in October, 34.8 per cent. In May, 1896, the canal would have taken 51.3 per cent of the total flow of the river for that month; in June, 12.2 per cent; in July, 15.9 per cent; in August, 19.2 per cent; and in September, 24.5 per cent. It appears, therefore, that the taking of 80 cubic feet per second from Genesee River for canal purposes is a very serious matter to the water power of the stream and is unjustifiable, unless it be clearly shown that the addition to the wealth of the State is greater

than if the water were used for supplying power. The actual damage resulting from taking at times 50 per cent of the unregulated flow of the stream is about as follows: As shown on a previous page, the minimum flow of the river is capable of producing 6,727 gross horsepower, or, what is the same thing, assuming 75 per cent efficiency, 5,046 net horsepower. One-half of the low-water power may therefore be taken at 2,523 net horsepower.

So long as the possibility exists of a draft upon the river equal to one-half of its minimum flow, this 2,523 net horsepower is practically rendered useless to its owners by reason of the uncertainty as to the exact time of the draft, or if not rendered useless, is far less valuable than if it were absolutely permanent power. In enforcing this view it may be pointed out that Rochester is a manufacturing town, made up chiefly of establishments using comparatively small quantities of power at each place, but that the power must still be continuous every day; that is to say, it must be absolutely permanent power. So long, therefore, as one-half the total minimum power of the stream is subject to stoppage during any month, the manufacturers will preferably use steam power, on account of its permanency, even at considerably greater expense. Bearing on this view, the fact may be pointed out that the use of soft coal in Rochester for steam purposes is stated as 500,000 tons a year, which, at an average price of $2.40 per ton, amounts to the sum of $1,200,000 annually. It may be considered settled, therefore, that water power is valuable at Rochester, and that anything which tends to reduce the permanent power 50 per cent is a very serious matter to the manufacturers of the city.

COMPARISON OF MOUNT MORRIS AND PORTAGE SITES.

As a final point in the discussion of Genesee River storage, comparison will be made between the Mount Morris project, storing 7,370,000,000 cubic feet, at a cost of $2,785,000, and the Portage project, storing 15,000,000,000 cubic feet, at an estimated cost of $2,600,000, for the purpose of determining the relative commercial advantages.

With the reservoir at Mount Morris storing 7,370,000,000 cubic feet there is 282 feet fall, on which 7,370,000,000 cubic feet, less the quantity required for the canal, may be applied for power purposes. As already explained, the constant outflow from the reservoir would never be less than 300 cubic feet a second. Continuous power development under this plan would, therefore, be based on 300 cubic feet a second at Mount Morris, something more than this at Geneseo and York, and on 600 cubic feet a second at Rochester. On this basis of computation it appears that the total permanent, continuous power to be realized from a reservoir storing 7,370,000,000 cubic feet and located in the Mount Morris Gorge would be 18,327 gross horsepower.

In regard to the increase in water power, the effective value of the storage will be the amount of permanent power above the low-water

power of the stream. As already stated, the total permanent power for the unregulated stream is 6,727 gross horsepower. The gain due to the storage is, therefore, 11,600 gross horsepower. Assuming a price of $10 per gross horsepower, we reach an annual return from the increased power of $116,000; but the Mount Morris reservoir is estimated to cost $2,785,000. If we assume the project carried out by a private company, with money at 5 per cent, the annual interest on the investment is $139,250—a sum $23,250 in excess of the probable annual income when all the power created shall have been brought into use; but there should be a sinking, maintenance, and repair fund of at least $25,000 a year, in order to repay the principal investment, which if taken into account increases the probable deficiency to $48,250 a year. It must be concluded, therefore, that with the present understanding as to the minimum run-off of Genesee River the project of a storage reservoir in Mount Morris Canyon, storing approximately 7,370,000,000 cubic feet of water, at a cost of $2,785,000, is commercially impracticable.

If we consider the Portage project in its financial aspects, where it is proposed to construct a reservoir storing 15,000,000,000 cubic feet of water, at a cost of $2,600,000, we reach the following results:

The total fall from just above the upper fall at Portage to the mean level of Lake Ontario is 785 feet, of which the greater portion is available for the development of water power. Without going into detail, we may place the permanent, continuous gross horsepower of the river, with a storage of 15,000,000,000 cubic feet at Portage, at the following figures:

Power of Genesee River after construction of reservoir at Portage.

	Gross horsepower.
Portage to Mount Morris	25,924
Mount Morris	835
Geneseo and York	624
Rochester	29,840
Total	57,223

Deducting from 57,223 gross horsepower the present permanent power of 6,727 gross horsepower, we have 50,496 gross horsepower as the net increase in the permanent water power of the stream due to the construction of the Portage reservoir. At $10 per gross horsepower, as before, the annual income when the power is utilized amounts to $504,960. The estimated cost of producing this vast increase in power is $2,600,000. Assuming an interest rate of 5 per cent, the annual interest is $130,000; adding to that amount $25,000 for sinking fund, maintenance, and repairs, the total annual expense becomes $155,000.. The difference of $349,960 is the net annual income.

As already shown, when interest is taken into account, the Mount Morris project becomes commercially impracticable. The Portage project, on the other hand, shows an annual income, above interest account, sinking fund, maintenance, and repairs, of $349,950, which,

capitalized at 5 per cent, represents $6,999,000. If we assume 4 per cent, the capitalization of the annual income may be expected ultimately to represent $8,748,750.

SUMMARY.

Lack of space prevents discussion in greater detail of the Genesee River storage project, and the following summation is presented as embodying the main points of the discussion:

(1) Of the several available sites for reservoirs on Genesee River that at Portage is preferable to others, because it affords the largest storage at the smallest cost per unit volume.

(2) Serious floods have occurred a number of times in Genesee River at Rochester, the most serious being that of March, 1865. At least $1,000,000 loss resulted from that flood. The flood in April, 1896, was nearly as severe as the flood of March, 1865, although, as the river channel was clear, very little damage ensued.

(3) As the result of three years' measurements of Genesee River, it is determined that the minimum flow of the stream may for the entire year be as low as 6.67 inches on the watershed.

(4) A study of existing conditions shows that the Genesee River drainage area has been nearly denuded of forests, and hence that severe spring floods are likely to be frequent. For the same reason the summer flow of the stream is less than formerly.

(5) As a tentative conclusion, based on the data at hand, it may be said that deforestation of a drainage area may tend not only to increase floods somewhat, but to decrease materially the amount of the annual run-off.

(6) A comparison of the conditions existing on the drainage area of Genesee River with those of the upper Hudson, which is still largely in forest, shows less run-off under given conditions from the Genesee than from the Hudson, thus indicating the probable effect of the forest in increasing the run-off.

(7) As regards the upper Genesee drainage area, the forest has been removed by landowners who have commercially profited by such romoval; the effect, however, has been to injure permanently every riparian owner on the stream; hence it is proper that the State should spend money either in partially reforesting the area or in constructing river regulation works. The latter is preferable, because the benefits can be realized in a few years. If the State does not desire to construct such works, there should be no obstacles interposed to their construction by a private company.

(8) The proposed Portage reservoir will impound 15,000,000,000 cubic feet of water, at an estimated cost of $2,600,000, or at a cost of $173.33 per million cubic feet stored. It affords a permanent, continuous power above the present low-water flow of the stream of 50,496 gross horsepower, while the reservoir at Mount Morris affords only 11,600 horsepower above the present low-water power of the stream.

(9) Based on manufacturers' ratings, the present total developed water power of Genesee River from Portage to Rochester, inclusive, is 19,178 net horsepower; or, basing the amount of water power on the manufacturers' ratings of water required, and assuming 75 per cent efficiency on the wheels, the total power is 17,248 net horsepower, of which 16,683 net horsepower is within the limits of the city of Rochester.

(10) The enlarged Erie Canal will require 80 cubic feet of water per second from Genesee River for every month of the navigation season except May, and in that month a mean of 177 cubic feet per second.

(11) The present extreme low-water power of Genesee River at Rochester is 5,046 net horsepower, of which one-half, or 2,523 net horsepower, will be rendered very much less valuable to its owners because of the taking for the enlarged Erie Canal of 80 cubic feet per second in every month of the navigation season and 177 cubic feet per second in May.

WATER STORAGE ON HUDSON RIVER.

As noted in Part I of this paper, on page 33, Hudson River is divided at the Troy dam into the upper or water-power section and the lower or tidal portion. The proposed reservoirs are, as a matter of course, in the upper section, that above Troy.

EARLY SURVEYS.

The project for constructing storage reservoirs on the upper Hudson has been agitated for many years, the first surveys for this purpose having been made in 1874. In that year Prof. F. N. Benedict conducted surveys, and in his report proposed an extensive system of reservoirs. The chief interest attaching to this report is the proposition on the part of Mr. Benedict to build storage reservoirs at Blue Mountain, Racket, Forked, Beach, and Long lakes, and divert the water stored on these several lakes from their natural drainage into Racket River, to the south, thus making them artificially tributary to Hudson River. In proposing this diversion, Mr. Benedict apparently assumed that the State, in its sovereign capacity, could divert waters from one drainage basin to another without regard to the rights or wishes of the riparian owners.

In addition to the lakes already enumerated, which are naturally tributary to Racket River, Mr. Benedict proposed to make reservoirs of the following lakes and ponds in the upper Hudson drainage area: Round Pond, Catlin Lake, Rich Lake, Harris Lake, Lake Henderson, Newcomb Lake, Lower Works reservoir, Chain Lakes, Goodenow Pond, Goodenow River reservoir, South Pond, Clear Pond, Slim Pond, Ackerman Pond, Perch Pond, Trout Pond, Lake Harkness, Shedd Lake, First Sergeant Pond, Third Sergeant Pond, Plumley

Pond, Moose Pond, and Cary Pond. The total storage to be furnished by the entire system of reservoirs is placed at 18,419,781,600 cubic feet. The total cost of the proposed reservoirs was placed by Mr. Benedict at about $265,000, or, including the diversion canal and improvements at Long Lake, at a total of about $460,000. The dams

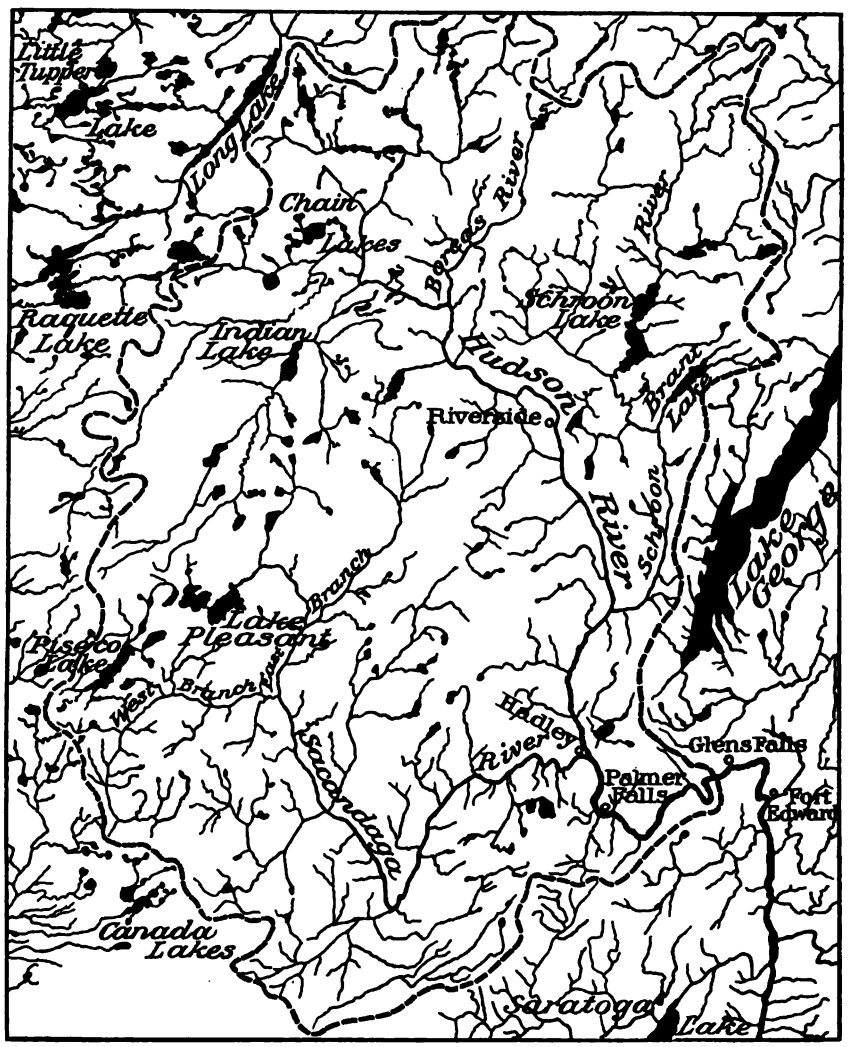


FIG. 1.—Map of drainage area of Hudson River above Glens Falls.

proposed were to be constructed of timber, very much after the plan of the timber dams still constructed by the lumbermen in this region, as shown on Pl. III.[1]

[1] For further particulars of Mr. Benedict's reservoir system, see Report on a Survey of the Waters of the Upper Hudson and Racket Rivers in the Summer of 1874, with Reference to Increasing the Supply of Water for the Champlain Canal and Improving the Navigation of the Hudson River, by F. N. Benedict, Ass. Docs. (1875), Vol. I, No. 6, p. 85.

A. LUMBERMAN'S DAM ON CEDAR RIVER

B LUMBERMAN'S DAM ON INDIAN RIVER

In 1874, when Mr. Benedict prepared his report, the demands for water upon Hudson River were far less extensive than at present, and even in 1882 the total water power of the stream was, according to the statistics of the Report on the Water Power of the United States, Tenth Census, only 12,894 horsepower, while in 1895 the total horsepower was 43,481. Taking into account additional wheels set in the last two years, as well as the extensive development of the Hudson River Power Transmission Company now in progress 3 miles below Mechanicville, it is probable that early in 1898 there will be wheels set on Hudson River capable of furnishing, at full capacity, not far from 55,000 horsepower. This great development has led to a very strong demand in the last few years for increased flow during the low-water period.

RECENT INVESTIGATIONS.

In 1895 a survey of the upper Hudson Valley was authorized with the view of determining what lakes and streams may be improved, and the water stored and diverted, in order to provide for the enlargement of Champlain Canal; for restoring to the water of Hudson River at or below Glens Falls the water diverted therefrom for canal purposes, and for improving the navigation of the lower Hudson River. The Hudson River naturally divides into two sections—the upper and the lower—at the Troy dam, which is the head of the lower or tidal section. The proposed reservoirs are all in the upper section, above Troy.

When one considers the scope of the investigation it may be readily seen that the studies must necessarily be of rather wide range. Special consideration should be given the following topics:

(1) The area of the several subdivisions of the drainage area, together with the locations and extent of the reservoir sites, and the total area from which the run-off can be controlled.

(2) The rainfall and mean temperature of the tributary region, as well as its physical characteristics, the relative amounts of timber and cleared area, etc.

(3) The actual run-off of the stream from the known area for a series of years, and a deduction therefrom by comparison with the rainfall and temperature records of the amount which may be stored in the year of minimum rainfall; also the relation which the run-off in the year of minimum precipitation bears to what may be expected in the average year, and a deduction therefrom of the proper height of flow lines for full-capacity development.

(4) The areas of the reservoirs and the losses therefrom by evaporation which may be reasonably expected, with the amount of effective storage which may be gained by the reservoir system when developed to full capacity.

(5) The amount of water now diverted for the use of Champlain

Canal, and the amount to be diverted for such use when the enlargement is completed; also the proper method of managing the system of reservoirs in order to secure the best results to the canal, the navigable section, and the water power.

(6) The amount of water power now in use on the stream and the effect of the present and future diversion.

(7) The regimen of the tidal section, and the effect of the unregulated fresh-water flow and of the construction of the system of impounding reservoirs.

(8) The cost of the reservoirs and the relation which the actual cost bears to the amount of storage gained. This latter element determines the commercial feasibility of the project.

RESERVOIR SITES ON SACUNDAGA, MAIN HUDSON, AND SCHROON RIVERS.

The surveys, so far as carried, indicate that economical reservoirs controlling the entire drainage area to full capacity in the year of minimum rainfall may be constructed in the Sacundaga, main Hudson, and Schroon valleys, as shown in the following paragraphs.

The Sacundaga River has, as already stated, a total drainage area above its mouth at Hadley of 1,040 square miles. The catchment areas of reservoir sites on Sacundaga River, in square miles, are as follows:

Catchment areas of reservoir sites on Sacundaga River.

	Square miles.
Lakes Pleasant and Sacundaga	45
Piseco Lake	55
Arietta flow	40
Miscellaneous	50
Total	190

The main Hudson or North River has a total drainage area above Hadley, not including Schroon River, of 1,092 square miles. Of this area the portions shown below may be developed to full capacity in the year of minimum rainfall:

Catchment area of reservoir sites on main Hudson River.

	Square miles.
Thirteenth Pond	14
Chain Lakes	58
Catlin Lake	25
Lakes Rich, Harris, and Newcomb, and the Goodenow flow	83
Lake Henderson	18
Lake Sanford and the Tahawus flow	67
Boreas River and Boreas Pond	45
Cedar River	58
Indian Lake	146
Total	514

Schroon River has a total drainage area above its mouth of 550. square miles. The topography of the Schroon area is such as to admit of two distinct lines of treatment—either to construct one large dam at Tumblehead Falls, about a mile below South Horicon, or to construct a series of 16 to 18 small dams at various points in the area. In either case it is possible to control substantially the full flow of the 502 square miles above Tumblehead Falls, and the decision of which is better will turn chiefly on the question of relative cost, the estimate taking into account the fact that it will cost much more to operate a large number of reservoirs than to operate one.

Catchment area of small reservoirs on Schroon River.

	Square miles.
Minerva Brook at Olmsteadville	43.4
Hewett Pond	2.5
Loon Lake	11.6
Friend Lake	4.9
Elk Lake	15.9
Clear Pond	2.3
New Pond	1.7
Deadwater Pond	18.9
Hammond Pond	11.4
Dudley Pond	3.9
Overshot Pond	4.9
Paradox Lake	31.6
Paragon Lake	5.6
Crane Pond	7.2
Pharaoh Lake	8.3
Brant Lake	38.7
Valentine Pond	6.7
Schroon Lake at Starbuckville	259.2
Total	478.7

The area between Starbuckville and Tumblehead Falls not available with the system of small reservoirs is 23.3 square miles.

The total controllable area of the upper Hudson, with the system of small reservoirs in the Schroon Valley, is as follows:

Total catchment area of upper Hudson River.

	Square miles.
Sacundaga Valley	190
Hudson above Hadley	514
Schroon Valley	479
Total	1,183

With one large reservoir in Schroon Valley the catchment area is increased to 1,206 square miles.

The system of small reservoirs outlined in the foregoing is estimated to store 15,330,000,000 cubic feet, at a cost of $1,172,500; hence the

cost per million cubic feet stored becomes $76.48. These figures, however, do not take into account the annual cost of maintenance and operation, which may be placed at $30,000 per year, and capitalized at 5 per cent is equivalent to a permanent investment of $600,000. Adding $600,000 to $1,172,500 gives a total permanent investment of $1,772,500.

A general estimate of the cost of the single large reservoir in Schroon Valley shows that with a dam at Tumblehead Falls 59 feet in height there would be impounded 15,925,000,000 cubic feet. The preliminary estimate indicates a total cost of $840,000, and a later survey indicates about $1,000,000. The final revision of the estimate on completion of the investigation may show a somewhat larger figure than this. Even if the cost were to be $1,100,000, it would still be exceedingly cheap storage, the cost for 15,925,000,000 cubic feet being on this basis only $69.14 per million cubic feet stored.

The dam at Tumblehead Falls would be located just below the outlet of Brant Lake, the elevation of the water surface of which is 801 feet. The flow line of the proposed reservoir has been placed at an elevation of 840 feet, thus giving a depth of 39 feet over the surface of Brant Lake, a depth of 33 feet over the surface of Schroon Lake, and a depth of 20 feet over Paradox Lake. With the reservoir full or nearly full, there would be continuous navigation from the head of Brant Lake to the head of Paradox Lake of about 35 miles. The villages of South Horicon, Bartonville, Starbuckville, and parts of Pottersville and Chester are within the flow line of this reservoir.

As another large reservoir to be built on the head waters of the Hudson, Indian Lake reservoir may be mentioned. As shown on page 128, the total controllable area at this lake is 146 square miles, which is capable of furnishing, in the year of minimum run-off, 4,468,000,000 cubic feet. To provide this storage, a dam raising the water surface 23 feet above the present dam is required. The storage of the present dam 10 feet in height is estimated at 800,000,000 cubic feet. In the spring of 1897 a private company, known as the Indian River Company, was organized to construct the Indian River reservoir. This company proposes to construct a masonry and concrete dam to the height of 23 feet above the old timber dam. The work is now in process of construction. The clearing of the margins of the lake includes the cutting of about 1,160 acres of timber.

The Indian River Company was the owner of considerable land bordering on and in the vicinity of Indian Lake. In consideration of the transfer of townships 15 and 32 of the Totten and Crossfield purchase to the State forest preserve board, that board has, in effect, purchased the dam in process of construction, which, with the clearing of the margins, is estimated to cost about $100,000. The forest preserve board stipulated that the superintendent of public works

have the right to draw water from the reservoir when necessary for the supply of Champlain Canal, the balance of the storage to be used by the Indian River Company for increasing the low-water flow of Hudson River for the benefit of the water power. At a total cost of $100,000 the cost per million cubic feet stored becomes $22.38. Taking into account the quantity of water stored at Indian Lake, this must be considered a very cheap reservoir.[1]

Piseco Lake may also be referred to as another large reservoir which may be constructed on the upper Hudson at low cost. It is estimated that a storage of 1,725,000,000 cubic feet may be made, at an expenditure of $70,000, or at an average cost per million cubic feet stored of $40.

Without going further into detail, the following may be given as the approximate storage of the entire upper Hudson system, worked out to date.[2]

Approximate storage of upper Hudson River.

	Cubic feet.
Storage of Sacundaga and main Hudson River drainage areas, not including Boreas River reservoir, Boreas Pond, Indian Lake, and Piseco Lake	14,364,000,000
Boreas River reservoir and Boreas Pond	1,111,000,000
Indian Lake	4,468,000,000
Piseco Lake	1,725,000,000
Schroon Valley	15,925,000,000
Hadley	4,000,000,000
Conklinville	4,000,000,000
Total	45,593,000,000

This storage is considered sufficient, in conjunction with the natural flow of the unregulated portion of the river, to maintain at Mechanicville a flow of at least 4,500 cubic feet per second during the entire year.

In addition to the reservoirs named above, the general investigations indicate that there is, possibly, an opportunity to make a large reservoir on Sacundaga River by the erection of a dam about 20 feet in height at Conklinville, where there is a reach of river extending 24 miles to Northville. The available storage of such a reservoir is taken at about 4,000,000,000 cubic feet.

There is also an opportunity to construct on the main Hudson at Hadley, just above the mouth of the Sacundaga, another reservoir of about 4,000,000,000 cubic feet capacity, at a point where the natural conditions for constructing such a reservoir are considered very good. At the site of the proposed dam the river shows a granitic rock bottom

[1] This dam was completed in 1898.

[2] For full details the reader is referred to the original reports on the upper Hudson storage surveys, in the Annual Reports of the State Engineer and Surveyor for the fiscal years ending September 30, 1895 and 1896.

with precipitous banks nearly 40 feet in height and about 100 feet apart. The material for a permanent stone dam exists in the vicinity, with an opportunity to construct a wasteway over natural rock at one side.

Inasmuch as all the storage except that of the Sacundaga area would pass through the Hadley reservoir, its construction would simplify the management of the system very greatly. In the summer season, as long as there is any storage above to be drawn upon, this reservoir could be kept nearly full and just the right quantity drawn out from day to day to keep the river at the assumed flow of 4,500 cubic feet a second at Mechanicville.

EFFECT OF PROPOSED STORAGE ON RIVER FLOW.

The foregoing quantities of storage have been fixed upon on the basis that the water yield of the year of minimum stream flow will furnish a storage of at least 12 inches, the flow line of the reservoirs themselves being located with reference to holding back 13.5 inches. If, however, one examines the tables of run-off of the Hudson at Mechanicville, given in Part I of this paper, on page 82, and of precipitation in the watershed, given on the next page, it is seen that much greater yields can be expected in an average year. From this point of view, it may be asked, Why not make the reservoirs somewhat larger than merely sufficient for the wants of the year of minimum flow and carry some water over from one year to another, thus more nearly attaining an absolute regulation of the river—not for a single year, but for a series of years? The chief objection to this method of procedure is that experience with other large reservoir systems is against other than a moderate development on this line, it having been repeatedly found that however high the flow line, reservoirs are likely to be nearly empty at the beginning of the storage period of the minimum year. Experience indicates that the rainfall and stream flow move in cycles, there being in each cycle several successive years of flow above the average. The demands for water tend to increase during the years of plenty, until those in charge apparently forget there will ever be a deficiency. The best practice, therefore, is to locate the flow line with reference to about the minimum yield, thus forcing an economy in the use of water from the beginning. By proceeding in this way provision may be made for carrying over moderate quantities of water from the latter end of the year more effectually than in any other way.

A. THE GEORGE WEST PAPER MILL, ON HUDSON RIVER AT HADLEY, NEW YORK.

B. THE HUDSON RIVER PULP AND PAPER COMPANY'S MILLS AT PALMER FALLS, ON HUDSON RIVER, NEW YORK.

Mean precipitation on the upper Hudson watershed.

[In inches.]

Month.	Albany.	Glens Falls.	Keene Valley.	Mean of Albany, Glens Falls, and Keene Valley.	Western Massachusetts.	Northern Plateau	Lowville Academy.	Johnstown Academy.	Cambridge Academy.	Fairfield Academy.	Granville Academy.	Mean of all.
December	2.71	3.19	2.75	3.01	4.31	3.57	2.14	2.91	2.36	2.78	2.48	2.92
January	2.75	3.16	3.00	3.03	3.36	3.88	2.35	3.30	3.36	2.69	2.08	2.99
February	2.49	3.03	2.22	2.64	2.83	3.60	2.43	2.86	2.61	2.06	1.42	2.56
March	2.72	2.72	2.24	2.50	2.94	2 52	1.78	3.63	2.12	2.36	1.74	2.48
April	2.80	2.15	2.09	2.14	2.02	2.39	1.91	2.93	3.36	2.53	2.13	2.43
May	3.62	3.10	3.05	3.14	3 17	4 46	2.79	3.45	3.65	3.04	3.47	3.38
	17.09	*17.35*	*15.35*	*16.47*	*18.63*	*20.42*	*13.40*	*19.08*	*17.46*	*15.46*	*13.32*	*16.76*
June	4.07	2.83	2.89	2.99	3.24	3.88	3.42	4.20	4.66	4.29	3.21	3.67
July	4.29	3.25	3.61	3.53	3.44	3.83	3.67	4.01	3.91	4.21	3.63	3.78
August	3.96	4.17	4.21	4.20	3.91	5.07	2.85	3.14	3.98	3.66	2.97	3.79
	12.32	*10.25*	*10.71*	*10.75*	*10.59*	*12.78*	*9.94*	*11.35*	*12.55*	*12.16*	*9.81*	*11.25*
September	3.43	2.96	3.00	3.13	3.51	3.57	2.84	2.87	3.27	3.08	2.67	3.12
October	3.58	2.36	2.49	2.60	3.41	3.06	3.29	3.20	3.60	3.56	2.90	3.15
November	3.08	3.24	3.56	3.26	2.84	3.46	2.94	3.33	3.29	2.46	2.88	3.11
	10.09	*8.56*	*9.05*	*8.99*	*9.76*	*10.09*	*9.07*	*9.49*	*10.16*	*9.11*	*8.45*	*9.38*
Total	39.50	36.16	35.11	36.22	38.98	43.29	32.41	39.92	40.17	36.73	31.58	37.39

The figures in the above table are obtained by averaging the results obtained at Albany from 1825 to 1895; at Glens Falls, from 1879 to 1895; at Keene Valley, from 1879 to 1895; in western Massachusetts, from 1887 to 1895; in Northern Plateau, from 1889 to 1895; at Lowville Academy, from 1827 to 1848; at Johnstown Academy, from 1828 to 1845; at Cambridge Academy, from 1827 to 1839; at Fairfield Academy, from 1828 to 1849; at Granville Academy, from 1835 to 1849; the mean of Albany, Glens Falls, and Keene Valley, from 1879 to 1895. Although the foregoing figures are here given in detail, later studies indicate that the mean rainfall of the Northern Plateau as defined by the State meteorological bureau is the best rainfall record to apply to the upper Hudson area.

The proposed regulation of Hudson River, as thus far planned, is to be arranged on the basis of maintaining a flow of at least 4,500 cubic feet per second at Mechanicville, where, as has been seen, the drainage area is 4,500 square miles, such a regulation being equivalent to producing at Mechanicville a constant flow of 1 second-foot per square mile. The relation of such regulated flow to the natural unregulated flow may be seen by studying the diagrams of flow of Hudson River at Mechanicville given in Part I, on page 81.

As regards the change in the regimen of the stream due to storage, it may be remarked that the reservoirs have been designed on the basis of giving to the stream at least 0.5 inch on the drainage area per month. This amounts to 0.45 cubic foot per second per square mile for a month of thirty days; it is not, however, intended to state that the entire river will ever be as low as 0.45 cubic foot per second per square mile, or, what is the same thing, as low as 2,025 cubic feet per second at Mechanicville, but only that those tributary streams on which the storage reservoirs are located may be down to this figure. With 0.45

cubic foot per second per square mile always flowing away from the controlled drainage area, the natural flow of the unregulated portion will usually furnish an additional amount sufficient to keep the river, during the storge period, up to nearly the assumed 4,500 cubic feet at Mechanicville; or in case of extreme low water in winter other reservoirs may be relied upon to assist in the manner already pointed out.

On the basis of 12 to 14 inches available storage, there may be, with 0.5 inch per month always going to the stream, a possible total requirement for the year of from 15 to 18 inches.

The table in Part I of this paper, on page 82, shows that the total flow for the water year 1895 was only 17.46 inches, or in that year there might have been a shortage if the reservoir system had been in operation of perhaps 0.5 inch. Any such shortage would necessarily have been carried over from the year 1894, when, in November, there was a run-off of 1.58 inches. Allowing 0.5 inch to the stream, from the November rainfall alone there would have been 1.08 inches remaining in the reservoirs to be carried over to 1895.

SUMMARY.

In conclusion, it may be said that it is entirely feasible to construct a system of reservoirs in the upper Hudson Valley, and such system may be designed with reference to the full capacity storage of at least 1,300 square miles of area, or 47 per cent of the total area above Glens Falls. Such control would result in the material reduction of floods at Glens Falls and other points.

The proposed total storage of 45,593,000,000 cubic feet would maintain 4,500 cubic feet per second flow, as well as supply the other necessary demands, in the driest season of the gaging period. The discharge measurements show that whereas the minimum unregulated flow at Glens Falls is as low as 900 cubic feet per second for a monthly mean, with the storage carried out, the probable monthly mean flow at Glens Falls will be at least 3,000 to 3,600 cubic feet per second. The minimum regulated flow of 4,500 cubic feet per second at Mechanicville will increase the low-water depth in Hudson River at Albany about 1.5 feet.

The diversion of water for the use of Champlain Canal is an injury to the water power at Glens Falls and lower points on the river. Since water power is much cheaper than steam power, the taking of the water of the river away from the manufacturers is a serious matter. In the fourteen years from 1882 to 1895 the use of water power on Hudson River has increased from a total of 12,894 net horsepower in 1882 to 43,481 net horsepower in 1895, an increase of 237 per cent.

The upper Hudson storage system is estimated to cost from $60 to $70 per million cubic feet stored, a sum considerably less than the cost of many other systems.

A. GLENS FALLS PAPER MILLS AT FORT EDWARD, NEW YORK.

B. DAM OF THE HUDSON RIVER POWER TRANSMISSION COMPANY DURING CONSTRUCTION, OCTOBER, 1897.

DEVELOPMENT OF WATER POWERS.

POWER DEVELOPMENT AT NIAGARA FALLS.

The possibility of water-power development at Niagara Falls has attracted attention for many years, the first utilization there having been made in 1725, when the French erected a sawmill near the point where the Pittsburg Reduction Company's upper works now stand for the purpose of supplying lumber for Fort Niagara. Between 1725 and the early years of the present century little is known of the use made of Niagara Falls power further than that sawmills were in operation there during the whole period. In 1805, however, Augustus Porter built a sawmill on the rapids, and in 1807 Porter & Barton erected a gristmill. In 1817 John Witmer built another sawmill at Gill Creek, and in 1822 Augustus Porter built a gristmill along the rapids above the falls. From that year to 1885, when the lands along the river were taken for a State park, a considerable amount of power was developed by a canal which took water out of the river near the head of the rapids and followed along the shore nearly parallel with the bank of the river. Mills were built between this canal and the river, and a part of the 50-foot fall between the head of the rapids and the brink of the American Falls was thus utilized. A paper mill was built on Bath Island at an early date.

In 1842 Augustus Porter, one of the principal mill owners at Niagara Falls, proposed a considerable extension of the then existing system of canals and races, and in January, 1847, in connection with Peter Emslie, he published a formal plan which became the subject of negotiations with Walter Bryant and Caleb S. Woodhull. An agreement was finally reached by which they were to construct a canal and receive a plot of land at the head of the canal, having a frontage of 425 feet on Niagara River, together with a right of way 100 feet wide for the canal along its entire length of 4,400 feet, and about 75 acres of land near the terminus, having a frontage on the river below the falls of nearly a mile. The canal constructed under this agreement passes through what is now the most thickly settled part of the city of Niagara Falls.

Ground was broken by Messrs. Bryant & Woodhull in 1853 and the work carried on for about sixteen months, when it was suspended for lack of funds. Nothing further was done until 1858, when Stephen Allen carried the work forward for a time; later, in 1861, Horace H. Day took up the matter and completed a canal 36 feet wide, 8 feet deep, and 4,400 feet long, by which the water of the upper river was brought to a basin near the brink of the high bluff of the lower river and at an elevation of 214 feet above the lower river. Upon the margin of this basin various mills have been constructed, to the wheels of which water is conducted from the canal and discharged through the bluff into the river below. The first mill built on this hydraulic canal was a small gristmill, erected by Charles B. Gaskill in 1870 on the site of the present large flouring mill of the Cataract Milling Company.

NIAGARA FALLS HYDRAULIC POWER AND MANUFACTURING COMPANY.

In 1877 the hydraulic canal and all its appurtenances were purchased by Jacob F. Schoellkopf and A. Chesbrough, of Buffalo, who organized the Niagara Falls Hydraulic Power and Manufacturing Company, of which Mr. Schoellkopf is still president. The following is a list of companies either now supplied or to be supplied with power by the Niagara Falls Hydraulic Power and Manufacturing Company.

Power furnished by Niagara Falls Hydraulic Power and Manufacturing Company.

WATER POWER.

Company.	Business.	Horse-power.
Central Milling Co	Flouring mill	1,000
N. Wood Paper Co	Paper and pulp	500
Schoellkopf & Mathews	Flouring mill	900
Pettebone Cataract Manufacturing Co.	Paper and pulp	2,000
Cataract Milling Co	Flour	400
Niagara Falls Waterworks		200
Thomas E. McGarigle	Machine shop	25
Cliff Paper Co	Paper and pulp	2,500
Total		7,525
ELECTRIC POWER.		
Pittsburg Reduction Co	Aluminum	3,500
Niagara Falls and Lewiston R. R. Co.		400
Cliff Paper Co	Paper and pulp	800
Lewiston and Youngstown R. R. Co.		200
Buffalo and Niagara Falls Electric Light and Power Co.	Light and power	600
Niagara Falls Brewing Co		150
Rodwell Manufacturing Co	Silver plating, etc.	75
Sundry small customers in Niagara Falls.		100
Francis Hook and Eye Co	Hooks and eyes	15
Kelly and McBean Aluminum Co	Aluminum	15
The National Electrolytic Co		1,000
Total		6,355
MECHANICAL POWER FURNISHED ON SHAFT.		
Oneida Co., Limited	Silver-plated ware and chains.	300
Carter-Crum Co	Check books	60
Total		360
Grand total		14,240

POWER HOUSE OF THE NIAGARA FALLS HYDRAULIC POWER AND MANUFACTURING COMPANY.

The contract made in 1852 between Augustus Porter, Walter Bryant, and Caleb J. Woodhull only conveyed lands to the edge of the high bank of Niagara River, but did not include the talus or slope between the edge of the high bank and the river, and only granted the right to excavate 100 feet down the face of the bank. In 1852, when this contract was made, the use of water power under higher heads than 100 feet was, so far as the United States was concerned, entirely unknown. Until recently the mills at Niagara Falls have not attempted to use more than 50 or 60 feet head; hence it resulted that although the capacity of the Niagara Falls Hydraulic Power and

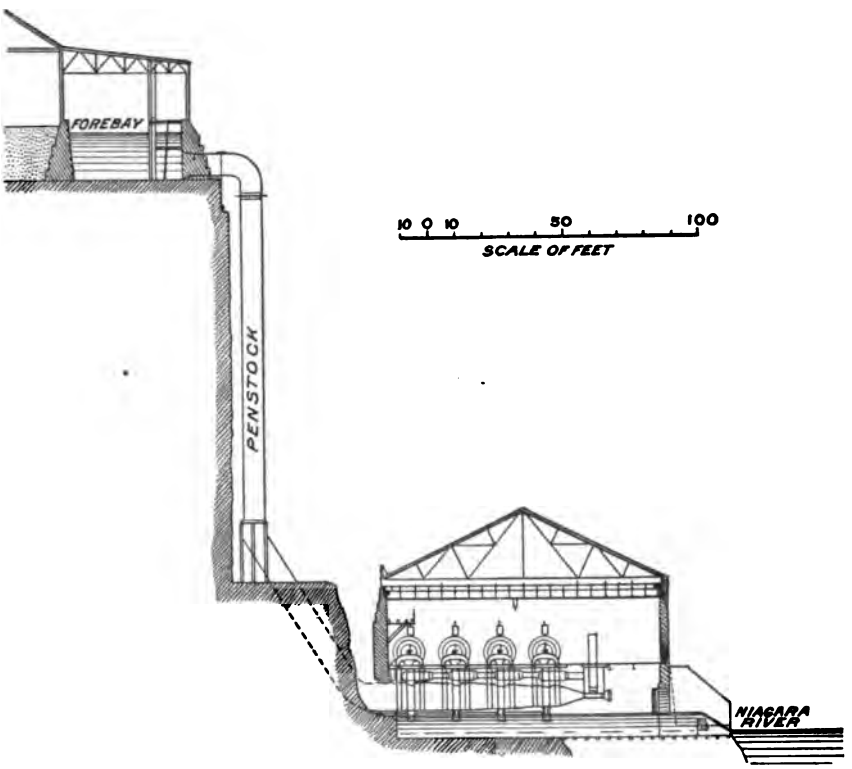


FIG. 2.—General plan of development of the Niagara Falls Hydraulic Power and Manufacturing Company.

Manufacturing Company's canal, as at first constructed, was sufficient, by development of the whole head, to produce about 15,000 horsepower, under the original agreements its capacity was exhausted when about 7,000 horsepower was produced.

In 1892 the Niagara Falls Hydraulic Power and Manufacturing Company began an enlargement and improvement of its canal. The plan adopted was to widen the original channel at one side to 70 feet, and make the new part 14 feet deep. This work is cut entirely through rock, below the water line. The enlargement of one side was completed in 1896. The canal as enlarged to date has a capacity

of about 3,000 cubic feet per second, giving, under present conditions, a total of from 40,000 to 50,000 horsepower, the cross section being about 400 square feet.

This company has a grant from the State of the right to draw from Niagara River as much water as can be taken through a canal 100 feet wide and 14 feet deep. Work on further enlargement is now in progress, and it is expected, within a year or two, to have a total of about 675 feet area of water section.

To July 1, 1897, about 100,000 cubic yards of material had been taken out at a cost of $250,000, the average cuttings in the original canal from the surface of the ground to the surface of the water being about 8 feet.

The development now in process by this company is very interesting. A bulkhead is located at the top of the high bank with a fore bay back of it connected with the main hydraulic canal by a short branch canal. From the fore bay a large penstock leads vertically down the cliff to a power house located directly on the shore of the lower river. In this power house horizontal turbine water wheels are placed, with dynamos directly connected, the power therefrom being transmitted either to the mills on the bluff above or to establishments at a distance. (See Pl. VII and fig. 2.) This company expects soon to transmit several thousand horsepower to Buffalo.[1] Without taking into account the cost of water in the canal, the cost of the development of power in the way in which it is now being developed by this company may be placed at $35 per horsepower.

NIAGARA FALLS POWER COMPANY.

The Niagara Falls Power Company has developed an extensive plant on quite different lines from that of the Niagara Falls Hydraulic Power and Manufacturing Company. In 1883 to 1885 Thomas Evershed, who was at that time division engineer of the western division of the New York State canals, was called on to survey Niagara Falls Park Reservation, as provided for by act of the legislature. This led Mr. Evershed to spend considerable time at Niagara Falls, during which he conceived the project of constructing a tunnel to begin at the level of the lower river and extend under the city of Niagara Falls for a distance of about 2½ miles. (See fig. 3.) This tunnel, as proposed, was to be generally parallel to the Niagara River, but at some little distance from it. At its head and at various points along the river from above Port Day it was proposed to construct branch canals

[1] For further details of the Niagara Falls Hydraulic Power and Manufacturing Company, see (1) Power development of Niagara Falls, other than that of the Niagara Power Company, by W. C. Johnson: Trans. Engineers' Society of Western New York, Vol. I, No. 6 (Feb. 3, 1896); (2) Niagara Falls Hydraulic Power and Manufacturing Company's new work, by Orrin E. Dunlap: Electrical Engineer, Vol. XX (Dec. 4, 1895); (3) Old hydraulic power plant at Niagara Falls transformed for electrical transmission, by Orrin E. Dunlap: Western Electrician, Vol. XIX (Dec. 5, 1896); (4) Pulp mill of the Cliff Paper Company of Niagara Falls, New York, by W. C. Johnson: Trans. Am. Soc. Civil Eng., Vol. XXXII (Aug., 1894).

PENSTOCK OF THE NIAGARA FALLS HYDRAULIC POWER AND MANUFACTURING COMPANY.

connecting with the river and through which water could be taken, to be discharged upon turbine wheels placed in vertical wheel pits and connected with the tunnel at various points.

The Niagara River Hydraulic Tunnel, Power and Sewer Company of Niagara Falls was incorporated in 1886 for the purpose of constructing and operating, in connection with Niagara River, a hydraulic tunnel or subterranean sewer for public use in the disposal of sewage and drainage and for furnishing hydraulic power for manufacturing purposes in the town of Niagara Falls. In consideration of the public service of sewerage and drainage, this company was authorized to acquire land by condemnation.

The general plan of development is described by Mr. Evershed in

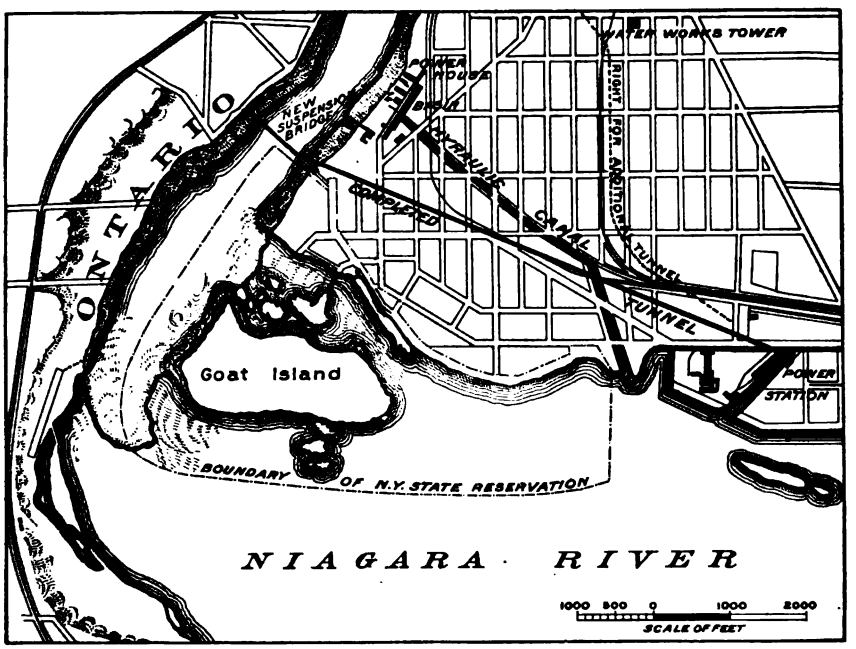


FIG. 3.—Map of Niagara Falls and vicinity, showing location of the great tunnel. (From Cassier's Magazine, Vol. VIII, p. 183.)

a report made July 1, 1896, in which he states that the main tunnel would begin at a point on the lower river immediately north of the State reservation, with its mouth as low as high water below the falls would permit. From this point to half a mile above Port Day it should have a rise of 1 foot in 100, or 52.8 feet per mile, and a section above Port Day equivalent to a circle 24 feet in diameter, the tunnel gradually diminishing in size in accordance with the number of mills emptying tail-water into it, until at the upper end it would have the same area of cross section as the connecting cross tunnels.[1]

The matter remained in abeyance until 1889, when the Niagara Falls

[1] See pamphlet, Water Power at Niagara Falls, prospectus of the Niagara River Hydraulic Tunnel, Power, and Sewer Company (1886).

Power Company was organized to carry out, in effect, Mr. Evershed's plan. The actual work of construction was undertaken by the Cataract Construction Company, composed of William B. Rankine, Francis Lynde Stetson, Pierpont Morgan, Hamilton McK. Twombly, Edward A. Wickes, Morris K. Jesup, Darius Ogden Mills, Charles F. Clarke, Edward D. Adams, Charles Lanier, A. J. Forbes-Leith, Walter Howe, John Crosby Brown, Frederick W. Whirtridge, William K. Vanderbilt, George S. Bowdoin, Joseph Larocque, John Jacob Astor, and Charles A. Sweet. This company has modified the original plans in some particulars, although the general scheme has been carried out.

The plan finally determined on comprised a surface canal 250 feet in width at its mouth on the river, 1¼ miles above the falls, extending inwardly 1,700 feet, with an average depth of 12 feet, and computed to furnish water sufficient for the development of about 120,000 horsepower. The masonry walls of this canal are pierced at intervals with inlets, guarded by gates. Some of these are used to deliver water to tenants who construct their own wheel pits and set their own wheels, while 10 of them are arranged on one side of the canal for the purpose of delivering water to the wheel pit of the Niagara Falls Power Company's power station, where dynamos, placed at the top of turbine vertical shafts, generate electricity for transmission. The wheel pit at the power station is 178 feet in depth and connected with the main tunnel by a short cross tunnel. The main tunnel as carried out has a maximum height of 21 feet and a width of 18.82 feet, making a net section of 386 square feet. The slope of this tunnel is 6 feet to the thousand.

The most careful consideration was given to the subject of the turbines to be used, as well as to the question of power transmission. In 1890 Edward D. Adams, who was then president of the company, established an International Niagara Commission, with power to offer $20,000 in prizes. This commission consisted of Sir William Thomson (now Lord Kelvin), Dr. Coleman Sellers, Lieut. Col. Theodore Turretini, Prof. E. Mascart, and Prof. W. C. Unwin. Inquiries concerning the best-known methods of development and transmission of power in England, France, Switzerland, and Italy were made, and competitive plans were received from twenty carefully selected engineers and manufacturers of power plants in England, Europe, and America. These plans were submitted to the commission, which awarded prizes to those considered worthy. The most important result was the selection of the designs of Faesch and Piccard, of Geneva, for turbines computed to yield 5,000 horsepower each. Three wheels have been built from these designs and are now in place and regularly operated.

Without going into details of the electrical work, it may be stated that the Niagara Falls Power Company adopted the two-phase alternating current system as best adapted to its work. In the dynamos employed the field magnet revolves instead of the armature. As

A. POWER HOUSE OF THE NIAGARA FALLS POWER COMPANY.

B. OUTLET OF TUNNEL OF THE NIAGARA FALLS POWER COMPANY

advised by the company's electrical engineer, Prof. George Forbes, of London, three such dynamos, of 5,000 horsepower each, constructed by the Westinghouse Company, of Pittsburg, have been installed. During the summer of 1896 a transmission line was constructed from Niagara Falls to Buffalo, and since November of that year some of the street railways in Buffalo have been operated electrically by power from Niagara Falls.

According to a statement of William B. Rankine, secretary of the Cataract Construction Company, the power furnished or contracted for by the Niagara Falls Power Company July 1, 1897, was as follows:

Power furnished by the Niagara Falls Power Company.

HYDRAULIC POWER.

Company.	Business.	Horse-power.
Niagara Falls Paper Company	Paper	7,200
ELECTRIC POWER.		
Pittsburg Reduction Company	Aluminum	3,050
The Carborundum Company	Abrasives	1,000
Acetylene Light, Heat, and Power Company	Calcium carbide	1,075
Buffalo and Niagara Falls Electric Light and Power Company.	Local lighting	500
Walton Ferguson	Chlorate of potash	500
Niagara Electro-Chemical Company	Peroxide of sodium	400
Buffalo and Niagara Falls Electric Railway	Local railway	300
Niagara Falls and Suspension Bridge Railway Company.*a*	....do	250
Buffalo Street Railway Company	22-mile transmission	1,000
Acetylene Light, Heat, and Power Company *b*	Calcium carbide	4,000
Mathieson Alkali Works *c*	Soda ash	4,000
Buffalo Street Railway Company		1,000
Buffalo General Electric Company *d*	Lighting	3,000
The Carborundum Company *e*	Abrasives	1,000
Niagara Falls Water Works Company		45
Power City Foundry and Machine Company		25
Albright and Wilson	Electro-chemicals	400
Total hydraulic power sold at Niagara Falls		7,200
Total electric power sold at Niagara Falls		14,545
Total electric power sold at Buffalo		5,000
Total		26,745

a All from October 1, 1896.
b From delivery, say, November 1, 1897.
c From June 1, 1897.
d From November 15, 1897.
e From June 1, 1897.

Recapitulation of the total power in use or furnished from Niagara Falls January 1, 1898, shows the following amounts:

	Horsepower.
Hydraulic power:	
Niagara Falls Power Company	7,200
Niagara Falls Hydraulic Power and Manufacturing Company	7,525
Electric power:	
Niagara Falls Power Company	19,545
Niagara Falls Hydraulic Power and Manufacturing Company	6,355
Mechanical power:	
Niagara Falls Hydraulic Power and Manufacturing Company	360
Total	40,985

The large demand for power from the Niagara Falls Power Company has necessitated the enlargement of the wheel pit and power house to more than three times their present capacity. The work upon this enlargement, sufficient to provide 35,000 additional horsepower, has been in progress since June, 1896, and is now approaching completion. With the completion of this extension the Niagara Falls Power Company will have available 50,000 horsepower; a portion of the increased power was ready for delivery January 1, 1898.

The 50,000 horsepower developed when the present extension is completed represents but one-half of the capacity of the present tunnel. This company has further secured the right of way for a second discharge tunnel, so that when the demand for power shall render it necessary the present plant may be duplicated, thus furnishing 200,000 horsepower in all. In addition to this large development on the American side, the Canadian Niagara Power Company, an allied corporation, now holds from the Canadian government an exclusive franchise granting to it the right to develop on the Canadian side at least 250,000 horsepower. The total possible power proposed to be developed in the future at Niagara Falls is about as follows:[1]

Power proposed to be developed at Niagara Falls.

	Horsepower.
Niagara Falls Power Company's present tunnel	100,000
Niagara Falls Power Company's second tunnel	100,000
Niagara Falls Hydraulic Power and Manufacturing Company's canal	150,000
Canadian Niagara Power Company's tunnels	250,000
Total	600,000

The developments now in progress at Niagara Falls are being carried out on very broad lines and probably furnish the best examples of modern hydraulic work. They certainly lead so far as the

[1] For an interesting discussion as to the effect of diverting large quantities of water from Niagara River for power purposes, see report of Clemens Herschel, made December 12, 1895, on the Diversion of Water from the Niagara River for Power Purposes by the Niagara Falls Hydraulic Power and Manufacturing Company and by the Niagara Falls Power Company, and the Unimportant Effect of such Diversion upon the River. Mr. Herschel bases his discussion on the data of the Lake Survey of an ordinary and usual flow of 265,000 cubic feet per second. Reasoning from this premise he concludes that even when 300,000 or 400,000 horsepower are in use the effect upon the depth of the river will be insignificant.

United States is concerned. A complete account of both works, giving details of all the engineering features, would make a large-sized monograph. From this point of view it is only possible to cite some of the sources of information.[1]

POWER PLANT AT MASSENA, ON ST. LAWRENCE RIVER.

Among the large power developments now under construction in the State of New York is that at Massena, on St. Lawrence and Grass rivers. According to statements made by John Bogart, consulting engineer, the power plant now under construction at Massena includes the excavation of a canal leading from St. Lawrence River to Grass River, a distance of 3 miles, the building of a power house, the installation of fifteen 5,000-horsepower electric generators, and the necessary equipment of turbine water wheels. The furnishing of the electric apparatus has been awarded to the Westinghouse Electrical and Manufacturing Company, and is said to be the largest contract for electric apparatus ever placed.

The plan of development adopted at Massena is to divert a portion of the water of St. Lawrence River from its natural channel by means of a canal, carrying it 3 miles across to Grass River, where, after operating turbines, it will pass by way of Grass River to the St. Lawrence at a point lower downstream. Just below where the canal takes water from St. Lawrence River, Long Sault Rapids are located, which have a fall of about 50 feet. Grass River runs nearly parallel to the St. Lawrence for several miles, flowing into the St. Lawrence a short distance below the foot of Long Sault Rapids. To the south of St. Lawrence River, and between it and the valley of Grass River, there is a comparatively level plateau.

The average width of Grass River from its mouth to above where the power canal will intersect it is from 250 to 300 feet, and its water surface, for this portion, is substantially on a level with the St. Lawrence below the rapids; hence the surface of Grass River at the point where the power canal strikes the stream is from 45 to 50 feet below the surface of the St. Lawrence at the head of the canal. The power station will be located on the north bank of Grass River, the tail-water dropping into that stream, which thus becomes, in effect, a tailrace for this power development. Making some allowance for increased depth of water in Grass River between the power station and its mouth, when receiving the tail water, and also some allowance

[1] The main facts in regard to the plant of Niagara Falls Power Company as herein embodied have been furnished by L. H. Groat, secretary of the company. For more extended information the reader is referred to (1) Cassier's Magazine, Vol. VIII (July, 1895), where may be found an account of nearly every phase of the Niagara Falls Power Company's development; (2) The Electrical World, Vol. XXX (Oct. 23, 1897), which may be consulted for a description of the extension of the wheel pit now in process; (3) Niagara Falls publication of the Niagara Falls Chamber of Commerce, issued in 1897; (4) the various numbers for 1897 of Greater Buffalo, a monthly publication devoted to promoting the prosperity of Buffalo and Niagara Falls. Engineering News and other technical journals may also be consulted.

for inclination of the water surface of the head canal, it is thought that an absolutely permanent power of about 40 feet will be obtained.

The work of constructing the head canal and preliminary work on the foundations of the power house are now under way. It is expected that the work will be completed in 1899. The canal will be 250 feet wide and 25 feet deep, this capacity being assumed as sufficient to furnish 150,000 horsepower. The work is being carried out by the St. Lawrence Power Company, which was organized under the laws of the State of New York, with a capital stock of $6,000,000. According to statements made, a large amount of power has been taken by an English syndicate, which intends to use it chiefly for electro-chemical manufacturing.

INLAND WATERWAYS.

TRADE AND COMMERCE OF HUDSON RIVER.

The importance of Hudson River as a great waterway of commerce is shown by Mr. Charles G. Weir in a report made in 1890. Aside from its own local trade the river absorbs all the traffic of the Erie, Champlain, Delaware, and Hudson canals, besides the great coal trade of the Pennsylvania Coal Company at Newburg and the Erie coal trade at Piedmont. The average season of navigation of the river is two hundred and forty days. The two principal industries on Hudson River, which add materially to the total tonnage, are ice and brick. The capacity of the ice houses on and near the river exceeds 4,000,000 tons, and the amount annually harvested is about 3,500,000 tons. The bricks manufactured on the river exceed 850,000,000.

The following statistics include the tonnage received at all points above Spuyten Duyvil Creek, and of the local shipment between points on the river. That shipped is credited only to the points from which it was shipped, no entry being made to the total tonnage of the amount received at local points from other local points. The total tonnage also includes all through freights shipped from points up the river that passed the mouth of Spuyten Duyvil Creek going south.

Tonnage and value of commerce on Hudson River above Spuyten Duyvil Creek.

Total tonnage of all shipping points on Hudson River during 1889, not including the tonnage coming through State canals (tons)	15,033,309
Value of same	$378,196,094
Total tonnage coming to and leaving tide water through State canals, 1889 (tons)	3,592,437
Value of same	$108,000,000
Increase of same over tonnage, 1888 (tons)	326,466
Grand total tonnage of Hudson River, including tonnage through State canals (tons)	18,582,596
Value of same	$485,735,094
Number of transportation companies for passengers or freight, not including steamboats or pleasure boats	30
Total number of passengers carried, 1889	5,000,000

In regard to the foregoing statement of the capacity of ice houses on and near the river, as made by Mr. Weir, it may be remarked that Charles C. Brown, in a report on Hudson River, which appears in the Eleventh Annual Report of the State Board of Health, gives a list of ice houses on Hudson River, with their capacity in 1889. According to Mr. Brown, the total capacity in that year was 2,908,000 tons, while the crop harvested frequently exceeds this quantity by 500,000 tons, which is stacked up outside and disposed of before the warm season begins. Mr. Weir's statistics, as stated, include the capacity of ice houses on and near Hudson River, while Mr. Brown's include only those actually on the river, which probably explains the apparent discrepancy in the statistics.

STATE CANALS.

EARLY HISTORY.

The idea of a water communication between Hudson River and the West via the valley of the Mohawk had been a favored one with the statesmen of New York for many years previous to the beginning of the present century; the early projects, however, were altogether with reference to improvement of the natural water channels and did not include the construction of artificial channels further than such channels might be necessary as connecting links. Thus Sir Henry Moore, governor of the colony of New York, proposed, in December, 1768, an improvement of the navigation of the Mohawk River at Little Falls by a sluice on the plan then used on the Languedoc Canal in France.

In 1788 Elkhannah Watson proposed to establish a water communication from Hudson River and Lake Ontario by way of Oneida Lake, Oneida River, and Oswego River, his plan being to connect Wood Creek with Mohawk River by a canal and to improve the Mohawk with locks.

In January, 1791, Governor George Clinton, in an address to the legislature, urged the necessity of improving the natural water channels in order to facilitate communication with the frontier settlements. Following this address, in February of the same year, a joint committee was appointed to inquire what obstructions in the Hudson and Mohawk rivers it would be proper to remove. As the result of this inquiry, an act was passed March 24, 1791, authorizing the commissioners of the land office to explore and survey the ground from Mohawk River at Fort Stanwix (now Rome) to Wood Creek with reference to constructing an artificial channel, and also to survey Mohawk and Hudson rivers for improvement by locks and to estimate the cost of the same. A sum not exceeding $500 was appropriated to pay the expense of such survey.

At that time the channel of commerce was by the Mohawk from Albany to Fort Stanwix in boats of about 5 tons burden. Going west

these boats carried from 1½ to 2 tons and on the easterly trip 5 tons. From Fort Stanwix there was a portage of 2 miles across the flats to Wood Creek, whence the course lay into Oneida Lake and River, and from thence into Seneca and Oswego rivers to Lake Ontario; or, from points farther west, up Seneca River to Lakes Cayuga and Seneca. At that time it cost from $75 to $100 per ton for transportation from Seneca Lake to Albany. The time occupied in going from Albany to Seneca Lake was twenty-one days, and in returning eight days.

The commissioners appointed under the act of March, 1791, were Elkhannah Watson, Gen. Phillip Schuyler, and Goldsborrow Bayner. On the 3d of January, 1792, the commissioners reported the cost of improving the route from Albany to Seneca Lake by locks and canals at $200,000, whereupon the legislature passed an act March 30, 1792, incorporating the Western Inland Lock Navigation Company, for the purpose of opening navigation by locks from Hudson River to Lakes Ontario and Seneca, and the Northern Inland Lock Navigation Company, charged with performing a like service from Hudson River to Lake Champlain. The capital stock of each company consisted of 1,000 shares of $25 each, but the companies were afterwards allowed a capital stock of $300,000 and an increase of the same from time to time. George Washington, the original promoter of canals in the United States, was the first president of the Western Inland Lock Navigation Company.

In March, 1795, an act was passed directing the State treasurer to subscribe 200 shares to these companies, of $50 each. State aid was again granted by an act passed in April, 1796, by which the Western Inland Lock Navigation Company was loaned $37,500, and a mortgage taken by the State on the company's property at Little Falls. In that year a route was opened from Schenectady to Seneca Falls for boats carrying 16 tons. The locks at Little Falls were first built of wood, then of brick, and finally of stone; the remains of the latter are said still to exist. Dividends were paid for a number of years on the stock of the company making these improvements. The tariff levied for a barrel of flour carried 100 miles was 52 cents, and for a ton of goods, $5.75.

Finally New York entered upon its era of inland-water improvements under the auspices of the State itself. On April 15, 1817,[1] an act was passed entitled "An act respecting navigable communication between the great eastern and northern lakes and the Atlantic Ocean," in which it was provided that whenever in the opinion of the canal commissioners it should be for the interests of this State that all the interest and title in law and equity of the Western Inland Lock Navigation Company shall be vested in the people of this State, it should

[1] The full authority for the construction of the Erie and Champlain canals may be found in two acts, the first being chapter 237 of the laws of 1816, passed April 17, 1816; the second being chapter 262 of the laws of 1817, passed April 15, 1817. There is more or less confusion of these two dates in early canal literature.

be lawful for the canal commissioners to pass a resolution to that effect. The act then provides a procedure for taking the property of this company after the passage of such a resolution by the canal commissioners. Following this act the rights of the company were soon transferred to the State, and the property operated for two or three years thereafter under State auspices. In 1821 the State collected the sum of $450.56 for tolls charged from Rome to the lower lock at Little Falls on account of transportation over the route formerly controlled by the Western Inland Lock Navigation Company.

Chapter 144 of the laws of 1813 incorporated the Seneca Lock Navigation Company for the purpose of constructing a canal from Cayuga Lake to Seneca Lake. The rights of this company were purchased by the State, pursuant to chapter 271 of the laws of 1825. The two companies, the Western Inland Lock Navigation Company and the Seneca Lock Navigation Company, may be considered the forerunners of Erie Canal.

About $100,000 was expended by the Northern Inland Lock Navigation Company on locks around the falls at Cohoes and for their improvement, all of which proved a total loss, the rights of the company being finally transferred to the State before navigation from Hudson River to Lake Champlain was actually opened.

The amount expended by the Western Inland Lock Navigation Company up to December, 1804, was $367,743, which was increased to $480,000 in 1813, and to a total of $560,000 before the works were finally transferred to the State. The mistake of first constructing wooden locks proved a severe loss to the company, as all the original locks at Little Falls, German Flats, and Rome rotted away in about six years. The facilities afforded by these companies were undoubtedly inadequate to the demands of the rapidly growing western section, and accordingly an active agitation finally began for some more extended means of communication.

The early work was, as we have seen, entirely in the direction of the improvement of natural channels, the extent of artificial channels for the whole route from Hudson River to Seneca Lake being only 15 miles. About 1803, however, the project for an artificial canal connecting Lake Erie with tide water in the Hudson was broached by Gouverneur Morris. In 1807 Jesse Hawley wrote a series of articles on the subject, and in 1808 the legislature directed the surveyor-general, Simeon De Witt, to make a survey of such a route. This survey was made by James Geddes, who reported on January 20, 1809. In 1810 the legislature appointed commissioners to prosecute further examinations. This commission made its first report in March, 1811. After discussing the route as proposed, from Hudson River to Lake Ontario, it recommended the inland route to Lake Erie with a direct descent from Lake Erie to Hudson River. Following this report a bill was passed by the legislature reappointing the commissioners of

the previous year, with the addition of Robert R. Livingston and Robert Fulton, and extending the powers of the commissioners and adding to the appropriation for its work. The war of 1812 came on, however, and the canal project was temporarily dropped until 1816, when De Witt Clinton presented a memorial to the legislature from the city of New York urging action toward the construction of the canal. Finally the act of April 15, 1817, was passed creating a permanent board of canal commissioners,[1] which entered at once upon its duties, and providing for the construction of artificial navigation from Lake Erie to tide water on Hudson River, and also from Lake Champlain to tide water on the Hudson. The dimensions of the proposed canals were fixed by the commissioners as follows: For Erie Canal a bottom width of 28 feet, surface width 40 feet, and depth 4 feet, with locks 90 feet long and 15 feet wide; for Champlain Canal a bottom width of 20 feet, surface width 30 feet, and depth 3 feet, with locks 75 feet long and 10 feet wide.

Ground was broken for Erie Canal at Rome, July 4, 1817, and the section from Utica to Seneca River completed October 22, 1819, a boat passing from Rome to Utica on that day. Champlain Canal was opened in part for navigation November 24, 1819. The route for Erie Canal from Seneca River west was also explored in 1819, and the final location, from Seneca River to Rochester, made in 1821. The principal engineers were James Geddes, Benjamin Wright, and Canvass White.

The annual report of the canal commissioners, dated January 31, 1818, gives details of the system adopted for the construction of the canal. They state that they had decided to complete the middle section first, 58 miles of which were put under contract during the year 1817, this portion being wholly on the summit level. The whole labor performed in 1817 was equal to the completion of 15 miles. In indication of the easy character of the work, the commissioners state that three Irishmen finished 3 rods of canal in 4 feet cutting in five and one-half days, and that on the 58 miles under contract only half a mile required puddling.

The engineer's original estimate of the cost of the middle section, completed in 1819, was $1,021,851. The actual cost was $1,125,983. This increase, as stated by the commissioners, was due to change of prism and structures.

While the State canals were in progress the Seneca Lock Navigation Company, authorized by chapter 144 of the Laws of 1813, had been engaged in constructing a canal between Seneca and Cayuga lakes, including a series of locks at Seneca Falls. On June 14, 1818, a loaded boat from Schenectady, 16 tons burden, passed the newly-constructed locks at Seneca Falls. Along Mohawk River the passage

[1] The permanent board of canal commissioners of 1817 included the following men: De Witt Clinton, president; Stephen Van Rensselaer, Samuel Young, Joseph Ellicott, and Myron Holley, their appointment having been first authorized by the act of April 17, 1816.

A. ERIE CANAL AT BUFFALO, NEW YORK

B. BLACK ROCK GUARD LOCK ON ERIE CANAL

of boats of this size was effected through the locks of the Western Inland Lock Navigation Company, Erie Canal not being open for navigation at that date. The locks at Seneca Falls cost $60,000. The toll charged during 1818 was equivalent to 9 cents per ton per mile.

Champlain Canal was, as stated, opened for navigation November 24, 1819, from the Hudson at Fort Edward to Lake Champlain. The estimated cost of this section was $250,000, but on account of changing its dimensions to the same size as Erie Canal the revised estimate amounted to $333,000. The canal was finally completed from Lake Champlain to Albany on September 10, 1823.

Work on Erie Canal proceeded during the years from 1820 to 1825, in the former year 94 miles being in operation and in the latter 363. It was finally completed from Albany to Black Rock on October 26, 1825, on which day the first boat ascended the Lockport locks and passed through the mountain ridge into Lake Erie. Uninterrupted navigation was thus obtained from that lake to the Atlantic Ocean for boats of an average of about 40 tons burden. The event was made a gala day the whole length of the canal.

The construction of Erie Canal was due to the unbounded perseverance and genius of one man—Governor De Witt Clinton—who, when one studies the early history of Erie Canal, stands forth as the colossal figure of the enterprise.

The total expenditure on Erie and Champlain canals to January 1, 1826, was $9,474,373.14, from which should be deducted for pay of engineers and commissioners, the acquisition of water rights, land damages, the construction of feeders, repairs, Black Rock Harbor, lowering Onondaga outlet, Salina and Onondaga side cut, Waterford and Troy side cuts, Troy dam, and Glens Falls feeder, the sum of $1,621,274. Hence the actual cost of construction of the canal proper was $7,853,099, which, on the aggregate length of 433 miles, equals $18,136 per mile, or, taking into account the various extensions enumerated and the engineering as necessary items of expenditure, the original cost per mile of the Erie and Champlain canals may be placed at $21,881 per mile.

Between 1825 and 1833 work was begun on a number of lateral canals—as, for instance, Oswego Canal, begun in 1826 and completed in 1828; Cayuga and Seneca Canal, begun in 1827 and completed in 1829; Chemung Canal, begun in 1831 and completed in 1832, and Crooked Lake Canal, begun in 1831 and completed in 1833. The total cost of all the canals, including interest on loans up to March 23, 1833, was $11,460,066.77.

Chenango Canal was begun in 1833. The total amount expended on all the canals, including original construction, extensions, maintenance, repairs, and interest on loans, to the end of 1834 was $13,798,438, and the total amount of tolls received from 1820 to 1834, inclusive, was $10,000,730.97—that is to say, at the end of ten years

from the original completion of Erie Canal the amount returned to the State was nearly 78 per cent of the total cost to that date. This fact is of the greatest interest because it indicates that from the very beginning the New York State canal system was operated as a purely business enterprise. It is clear, then, that in reality the State of New York, in constructing its internal navigation system, went into the transportation business; by that statement it is meant that the State managed the affairs of the canals precisely as a private company would have managed them—that is, the State built its canal system and levied as heavy tolls as the articles transported would stand.

By way of illustrating how thoroughly the State was in the transportation business and on exactly the same basis as transportation companies, it may be cited that in 1830 the legislature sent a communication to the commissioners of the canal fund asking if it were not possible to increase the rate of toll on many of the articles transported, and stating that it seemed necessary, in order to meet all the interests involved, that the canals yield somewhat greater revenue. The commissioners replied to this communication at length, giving in detail the amount of toll levied on different articles transported, and finally concluded with the statement that it would be impossible to increase the tolls materially, because the articles transported were at that time taxed all they would stand. If the rate of toll were made materially greater, many articles would not be transported on the canals, but would go by other channels, as by St. Lawrence River and by the Great Lakes. The State would thus lose the benefit derived from carrying them.

About 1833 to 1835 railroads began to attract attention as means of transportation, and in 1835 John B. Jervis, Holmes Hutchinson, and Frederick C. Mills, who were the principal canal engineers of that day, were instructed to report on the relative cost of transportation on canals and railroads. In an introduction to their report by William C. Bouck and Michael Hoffman, canal commissioners, it is stated that it will not be difficult to show that the expense of transportation on railroads is materially greater than on canals. But in addition to this there were other important considerations in favor of canals:

(1) A canal may be compared to a common highway on which every man can be the carrier of his own property, therefore creating the most active competition, and thus reducing the expense of transportation to the lowest rates. The farmer, merchant, and manufacturer can avail themselves of the advantages of carrying their own product to market in a manner best comporting with the interest of each individual.

(2) Much of the property carried on the canals is carried by transportation companies, although the largest portion is carried by individuals and small associations. The individual who becomes the

carrier of his own product has the advantage of paying nearly one-half of all the expense of transportation in the regular course of his business, and the cash disbursements do not often much exceed the payment of the tolls. To the farmer the profits on return freight, in many instances, give a full indemnity for the expense of taking his cargo to market. On railroads, on the other hand, the proprietors must necessarily be the carriers.

A fixed popular belief in the two principles laid down by Messrs. Bouck and Hoffman in their introduction to the transportation report of 1835 has been the cause of a great deal of mistaken policy in the State of New York. For instance, nearly every year since the beginning of the railway era the newspapers of the State have teemed with the statement that the State must necessarily maintain the canal system in order to check the exorbitant tariff demands of competing railways. As we have seen, in 1830, just before the beginning of the railway era, the State was taxing every article transported upon the canals all that it would stand, and the system of excessive State tariffs was continued until a few years later, when the competition of the railways forced a reduction in the tariff for transportation on the canal.

GROWTH AND DECLINE OF CANAL TRANSPORTATION.

A number of reports bearing on transportation questions were submitted in 1835, and finally the fixed policy was adopted of enlarging Erie Canal, the act authorizing what is known as the Erie Canal enlargement being passed in that year. The law authorizing the enlargement directed the construction of double locks and a prism with a width at water surface of 70 feet, and a depth of 7 feet, the locks to be 110 feet long and 18 feet wide. It was estimated that an enlargement to this extent would save 50 per cent in cost of transportation, exclusive of tolls. The enlargement to this standard width and depth was begun in 1836 and continued to 1842, when the legislature directed the suspension of expenditures. In 1847 the work of enlargement was resumed, and substantially completed in 1862. Since that time to the work now in progress under the authority of chapter 79 of the laws of 1895 there has been no change in the standard of width at water line of 70 feet and depth of 7 feet. As an interesting fact it may be pointed out that while the enlargement authorized in 1835 led to vast increase in the transportation business on the State canals the cost of transportation gradually decreased, one chief cause of such decrease being the competition of railways, until in 1883 the competition from this source became too sharp to maintain longer transportation on the canals if any toll at all were charged. The canals were then made free by legislative enactment.

The popular notion, formerly prevalent in New York, that it has been necessary to maintain the State canals in order to regulate the railways, is seen to be far from true. The railways have regulated the canals quite as much or more than the canals have regulated the railways. Indeed, the railways must be considered as having the better of it, because the State has been obliged absolutely to do away with all tolls on the canals in order to insure their obtaining business at all.

In illustration of the value of the water resources afforded by the Great Lakes in conjunction with the New York State internal navigation system, the following statement of receipts of flour, wheat, corn, oats, barley, and rye at Buffalo for certain years, from 1836 to 1896, inclusive, is given.

Receipts of flour, wheat, corn, oats, barley, and rye at Buffalo from 1836 to 1896.

Year.	Flour.	Wheat.	Corn.	Oats.	Barley.	Rye.
	Barrels.	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*	*Bushels.*
1836	139,178	304,990	204,355	28,640	4,876	1,500
1840	597,142	1,004,561	71,337	.....	.....	.....
1845	746,750	1,770,740	54,200	23,300	.....	.....
1850	1,103,039	3,681,347	2,593,378	357,580	3,627	.....
1855	937,761	8,022,126	9,711,430	2,693,222	62,304	299,591
1860	1,122,335	18,502,615	386,217	1,209,594	262,158	80,822
1865	1,788,393	13,437,888	19,840,901	8,494,799	820,563	877,676
1870	1,470,391	20,556,722	9,410,128	6,846,983	1,821,154	626,154
1875	1,810,402	32,987,656	22,593,891	8,494,124	916,889	222,126
1880	1,317,911	40,510,229	62,214,417	649,351	335,925	743,451
1885	2,993,280	27,130,400	21,028,230	767,580	577,230	309,370
1890	6,245,580	14,868,630	44,136,660	13,860,780	5,165,700	1,281,030
1895	8,971,740	46,848,510	38,244,960	21,943,680	10,253,440	787,340
1896	10,384,184	54,411,207	47,811,010	40,107,499	16,697,744	4,404,354

A comparison of the statistics of railroad and canal traffic shows at once the vast preponderance of freight carried by the several railways centering at New York in comparison with that carried by Erie Canal. In spite of the fact that the canal was made free in 1883, figures indicate that since that time there has been a continual decrease in the amount of freight carried on the canals. Probably no feature of this change is more significant than that of the internal movement in New York State. In 1889 the total movement within the State was 1,438,759 tons, while in 1896 it was only 565,482 tons. These statistics show at once the decreasing estimation in which Erie Canal as a means of transportation is held by the great body of shippers in the State of New York. One of the results of this decrease is graphically

EFFECT OF DECREASE OF BUSINESS ON ERIE CANAL.

depicted in Pl. X, showing the fleet of boats tied up and awaiting business.

By way of illustrating the growth and decline of the business of the New York State canals from about 1835–36 to the present time the following statement of total tonnage of all freight on the canals, ascending and descending, and the value of the same for certain years from 1837 to 1896, inclusive, is presented:

Tonnage of freight on New York State canals and value of same, 1837 to 1896.

Year.	Tons.	Value.
1837	1,171,296	$55,809,288
1840	1,416,046	66,303,892
1845	1,977,565	100,629,859
1850	3,076,617	156,397,929
1855	4,022,617	204,390,147
1860	4,650,214	170,849,198
1865	4,729,654	256,237,104
1870	6,173,769	231,836,176
1875	4,859,958	145,008,575
1880	6,457,656	247,844,790
1885	4,731,784	119,536,189
1890	5,246,102	145,761,086
1895	3,500,314	97,453,021
1896	3,714,894	100,039,578

Without analyzing the figures in detail, it is sufficient to point out that if it is true, as popularly supposed, that Erie Canal ought to be maintained as a medium of competition with the railways, the figures derived from the annual statements of the chief competitor of Erie Canal must be taken as conclusive that the competition has, on the whole, been a failure. The railway, developed as a private enterprise, has not only been able to carry freight as cheaply as the canal, but has been able to charge for the same and do the work at a profit. In the year ending June 30, 1897, the New York Central and Hudson River Railway Company paid a dividend on its stock of $4,000,000, besides carrying $51,866.80 to the surplus account, whereas the canal, although all tolls were removed in 1883, has still been unable to compete. Among the chief reasons for this result we may mention lack of organization of the canal system. The perpetuation of the idea that one advantage of the canals was that they were common highways on which each man could carry his own products to market has tended largely to produce this unsatisfactory result. Thus far there has never been any systematic organization for obtaining business for the canal. The boats are owned by small proprietors, each operating from one to three or four boats. When cargoes in hand are discharged

at either terminus, each owner solicits another cargo. The results are delays, half cargoes, and consequent loss. During the last few years it has been only by the most rigid economy that Erie Canal boatmen could live. On the other hand, the business of soliciting freight for the railways is compactly organized and every possible advantage taken of the situation.

However unsatisfactory it may seem to the individual boatman, the future of effective transportation on Erie Canal depends, in the opinion of the author, on the organization of large transportation companies which conduct the business of carrying freight by canal on the same business basis as adopted by railways. As to the equity of the State furnishing and maintaining a waterway on which transportation may be conducted by such corporations at a profit the author expresses no opinion further than to point out that the official discussion of such a proposition by the State engineer and surveyor in his annual report for the year ending September 30, 1896, may be taken to indicate that the day of Erie Canal as a State waterway has passed.

COST AND REVENUES OF THE NEW YORK STATE CANAL SYSTEM.

The accompanying table exhibits the total cost of construction, maintenance and operation, and the total revenues from all sources of the several canals of New York from their original inception to September 30, 1892.

Cost of construction, maintenance and operation, and revenues of New York canal system.

Canals.	Cost of construction.	Cost of maintenance and operation.	Total cost.	Revenue from all sources.	Loss.	Gain.
Erie and Champlain	$57,688,676	$41,582,759	$99,271,435	$128,191,068	.....	$28,919,633
Oswego	4,643,921	3,736,676	8,380,597	3,715,567	$4,665,030	.....
Cayuga and Seneca	1,886,662	1,157,754	3,044,416	1,055,016	1,989,400	.....
Black River	4,077,882	2,082,251	6,160,133	305,663	5,854,470	.....
Oneida River improvement	233,962	41,236	275,198	214,428	60,770	.....
Oneida Lake	513,439	144,060	657,499	65,180	592,319	.....
Baldwinsville (so called)	31,000	18,089	49,089	1,261	47,778	.....
Seneca River towing path	1,602	20	1,622	7,782	.....	6,160
Cayuga Inlet	2,020	948	2,968	7,534	.....	4,566
Crooked Lake (abandoned)	395,092	424,658	819,750	45,490	774,260	.....
Chenango (abandoned)	4,807,952	2,105,217	6,913,169	744,027	6,169,142	.....
Chemung (abandoned)	1,512,041	2,022,259	3,534,300	525,565	3,008,735	.....
Genesee Valley (abandoned)	6,741,839	2,814,809	9,556,648	860,165	8,696,483	.....
Total	82,536,088	56,130,686	138,666,774	135,738,746	31,858,387	28,930,359

The total cost of Crooked Lake, Chenango, Chemung, and Genesee Valley canals, which were abandoned under the provisions of the law of 1877, was $20,823,867, and the total revenue from all sources $2,175,247. The total loss on the abandoned canals was, therefore, $18,648,620. The following is the complete financial exhibit of all canals from their inception to September 30, 1892: Total loss on abandoned canals, $18,648,620; net gain on canals now in operation, $15,720,592; loss on the whole system, $2,928,028.

IMPROVEMENT OF ERIE CANAL.

The canal improvement now in progress was formulated by State Engineer and Surveyor Horatio Seymour, jr., about 1878 or 1879. In his annual report for the fiscal year ending September 30, 1878, Mr. Seymour discusses extensively transportation questions as related to Erie Canal, pointing out that transportation can be cheapened in two ways—by increasing the tonnage of boats or by increasing their speed. As to increasing the tonnage of boats, he states that two methods may be used—the locks may be lengthened or the depth of water may be increased. He refers to experiments made by Elnathan Sweet by which it was shown that the best form of waterway should have a cross section 5.39 times the immerged section of the boat, and a surface width 4.5 times the width of the boat. The width of the canal, Mr. Seymour states, is substantially what it should be, but it lacks the necessary depth in order to conform to the law of relation of cross section of water to immerged section of boat, as determined by Mr. Sweet. Reports are submitted showing that an additional depth of 1 foot could be obtained for about $1,100,000.

The matter of making the improvement, however, remained in abeyance until the passage of an act in 1895, which provided for submitting to the people at the State election in November of that year the question as to whether an improvement by deepening 2 feet should be undertaken, at an expense of $9,000,000. Section 3 of chapter 79 of the laws of 1895 reads as follows:

Within three months after issuing of the said bonds the superintendent of public works is hereby directed to proceed to enlarge and improve the Erie Canal, the Champlain Canal, and the Oswego Canal; the said improvement to the Erie and Oswego canals shall consist of deepening the same to a depth of not less than 9 feet of water, except over and across aqueducts, miter sills, culverts, and other permanent structures, where the depth of water shall be at least 8 feet, but the deepening may be performed by raising the banks wherever the same may be practicable; also the lengthening or improving of the locks which now remain to be lengthened, and providing the necessary machinery for drawing boats into the improved locks, and for building vertical stone walls, where, in the opinion of the State engineer and surveyor and superintendent of public works, it may be necessary. The improvement upon the Champlain Canal shall consist in deepening the said canal to 7 feet of water, and the building of such vertical stone walls

as, in the opinion of the State engineer and surveyor and superintendent of public works, may be necessary.

The necessary preliminary work was so far completed that bids for constructing the improvement were called for in October, 1896, and shortly thereafter contracts for work amounting to about $4,000,000 were awarded. The canal was closed December 1, 1896, and soon after work was begun and continued until May 5, 1897, when navigation was opened for the season of 1897, and all contractors not working with dredges discontinued operations until the winter of 1897–98. The act authorizing the present improvement provided, as we have seen, that the deepening of the canal prism might be accomplished either by excavation or by raising the side walls. As a matter of fact, sometimes one method and sometimes the other has been followed, depending upon the conditions of each level. Usually, however, a part of the increased depth has been obtained by raising the side walls, with the balance secured by excavation.

As is indicated in the extract from the act authorizing the present improvement, the work includes the lengthening of such locks as have not been previously lengthened. The original locks of the enlargement of 1836 to 1862 were 110 feet long by 18 feet wide. In 1885 work was begun lengthening these locks to 220 feet, or about 210 feet in the clear, thus permitting two boats to pass through at one lockage. Up to the present time 42 of the 72 original locks have been lengthened. The 30 locks yet remaining to be dealt with are mostly bunched in groups or flights, as, for instance, at Cohoes, where 16 locks effect a change of level of 140 feet, and at Lockport, where 5 locks effect a change of 58 feet. In order to lengthen locks built in flights it would be necessary to entirely reconstruct them, and as the restricted space, especially at Lockport, would render this a very difficult thing to do in one winter season, it has therefore been proposed to construct at Cohoes and Lockport, and possibly at Newark, vertical lift locks to take the place of the ordinary locks now in use at these places. The State engineer and surveyor has completed the plans for the proposed lift lock at Lockport, which is so located as not to interfere with the use of the locks now in place there during its construction. It has been announced that the $9,000,000 appropriated will fall about $7,000,000 short of completing the work of deepening and lengthening on the lines thus far carried out, and in consequence the matter of building the lift locks is held in abeyance.[1]

[1] For engineering and other details of the canal improvement now in progress see Eng. News, Vol. XXXVIII (Sept. 2, 16, and 23, 1897). See also Effect of depth upon artificial waterways, by Thomas C. Clark: Trans. Am. Soc. Civil Eng., Vol. XXXV, pp. 1–40. Also Eng. News, January 6, 1898, for discussion of the question, What shall New York do with its canals?

DESCRIPTION OF THE CANALS NOW IN OPERATION, AND THEIR WATER SUPPLY.

Following are some of the main facts in regard to the principal canals—Erie, Champlain, Oswego, and Black River—now in operation in the State of New York. Similar facts for Oneida Lake Canal, Oneida River improvement, the Cayuga and Seneca Canal, and others, may be obtained by reference to the annual reports of the superintendent of public works.

Length, capacity, and cost of New York State canals.

ERIE CANAL.

	Original canal.	Enlargement.
Length, in miles	363.00	351.78
Lockage, in feet	675.50	645.80
Average burden of boats, in tons	70.00	210.00
Maximum burden of boats, in tons	76.00	240.00
Construction authorized	Apr. 15, 1817	May 11, 1835
Construction completed	Oct., 1836	Sept., 1862
Actual cost of construction	$7,143,789	$44,465,414

CHAMPLAIN CANAL.

Length of canal, in miles	66
Length of feeder, in miles	7
Length of pond, in miles	5
Total, in miles	78
Construction authorized	Apr. 15, 1817
Glens Falls feeder authorized	Apr., 1822
Estimated cost of canal	$871,000
Total cost of canal and feeder to 1868	2,378,910
Total cost, including improvements and enlargements, to 1875	4,044,000

OSWEGO CANAL.

	Original canal.	Enlarged canal.
Length, in miles	38.00	38.00
Lockage, in feet	154.85	154.85
Average burden of boats, in tons	62.00	225.00
Construction authorized	Apr., 1825	Apr., 1854
Construction completed	Dec., 1828	Sept., 1862
Actual cost of construction	$565,473	$4,427,589

Length, capacity, and cost of New York State canals—Continued.

BLACK RIVER CANAL.

Length of canal, Rome to Lyons Falls, in miles	35.00
Length of improved river to Carthage, in miles	42.00
Length of navigable feeder, in miles	10.50
Lockage, in feet	1,082.25
Average burden of boats, in tons	48.00
Construction authorized	Apr., 1836
Construction completed	1849
Actual cost of construction	$3,581,954

EASTERN DIVISION OF ERIE CANAL.

Erie Canal is divided into three divisions, known as the eastern, the middle, and the western. The eastern division embraces the portion of the canal, with its feeders and side cuts, extending from the Hudson River at Albany to the dividing line between the counties of Herkimer and Oneida, and the whole of the Champlain Canal, with its feeders, ponds, and side cuts. The entire mileage of canals, feeders, and river improvements on the eastern division is as follows:

Mileage of eastern division of Erie Canal.

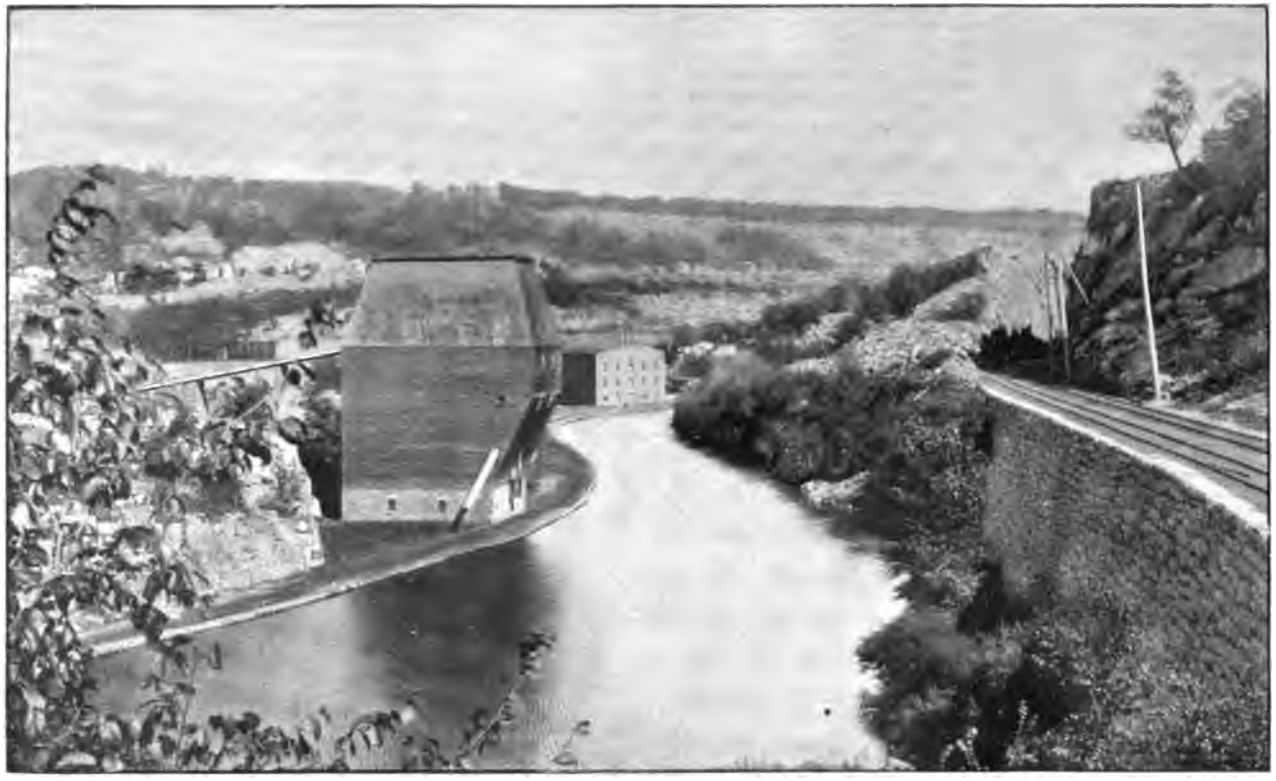
	Miles.
Erie Canal, Albany to east line of Oneida County	106.24
Fort Schuyler and West Troy side cuts	0.35
Albany basin	0.77
Champlain Canal, including Waterford side cut	66.00
Navigable river above Troy dam	3.00
Glens Falls feeder	7.00
Navigable river above Glens Falls feeder dam	5.00
Total	188.36

Mileage of unnavigable feeders of the eastern division of Erie Canal.

	Miles.
Mohawk River at Rexford Flats	0.39
Mohawk River at Rocky Rift	3.92
Mohawk River at Little Falls	0.19
Schoharie Creek	0.63
Total	5.13

WATER SUPPLY OF THE EASTERN DIVISION.

To the west of Little Falls, on the Erie Canal, lies 19.2 miles of the eastern division, supplied from the reservoirs and streams of the middle division East of Little Falls the supply is from Mohawk River, through Little Falls, Rocky Rift, and Rexford Flats feeders, and from Schoharie Creek through Schoharie Creek feeder. As to the quantity of water used on that portion of Erie Canal included in the eastern division very little is known. With the exception of a few thousand cubic feet per minute received from the middle division, the supply is, as just indicated, all derived from Mohawk River and



ERIE CANAL AT LITTLE FALLS, NEW YORK.

its tributary, Schoharie Creek. Thus far no measurements of the actual quantity used have been made. Probably the total diversion amounts in dry weather to from 500 to 600 cubic feet per second. Some of this is returned to Mohawk River by leakage and wastage, but just what proportion is returned, and what finally delivered either into Hudson River at Albany or by the Troy and Fort Schuyler side cuts, is not known. In view of the magnitude of the power development on Mohawk River at Cohoes it appears very desirable that such a determination be made.

The water supply of Champlain Canal is derived from Wood Creek and several small streams to the north of Fort Edward, Glens Falls feeder, Hudson River feeder, from Hudson River itself at Saratoga dam, and from Mohawk River at the Cohoes dam. An investigation of the amount of water diverted from Hudson River for the supply of Champlain Canal was made by the author in the fall of 1895.

As already stated, Champlain Canal is fed from Hudson River by Glens Falls feeder, which connects with the river about 2 miles above Glens Falls and from the Saratoga dam at Northumberland.

The length of Glens Falls feeder, from the guard lock at its head to where it enters Champlain Canal, about 2 miles above Fort Edward, is 6.92 miles. From this point the water in the canal flows both north and south, the total length of canal fed by Glens Falls feeder being 31.81 miles. Fort Edward level, into which Glens Falls feeder delivers water, is a summit level, and hence the water delivered into it, less the losses by percolation, evaporation, etc., is partly discharged into Lake Champlain and partly into Hudson River at Saratoga dam. Champlain Canal crosses through the pond formed by Saratoga dam from the east side to the west of the Hudson and again passes out of the river, taking a full supply therefrom at the village of Northumberland, from which point to Mohawk River at Cohoes the distance is 27.06 miles. The water from this section by passing into the Mohawk finally reaches the Hudson above the Troy dam. The canal crosses Mohawk River at Cohoes, taking water therefrom to supply the section from Cohoes to near West Troy, a distance of 2.36 miles. A small amount of water also passes from Champlain Canal to the Hudson through the Waterford side cut.

Since the construction of Glens Falls feeder there have existed serious leaks though the seamy limestone rock in which the feeder is excavated at and below the village of Glens Falls. It is claimed that the losses through these seams have generally increased, until for several years past they have amounted to about 50 per cent of the total flow into the feeder at the guard lock.

This leakage has been repeatedly complained of by the owners of water power at Glens Falls and several attempts to check it have been made, but without much avail. The river falls 38 feet at Glens Falls, and the owners of the water power there claim that this leakage,

which is practically all below the falls, is a detriment to their water power which ought not to exist. In order to determine the amount of this leakage, as well as the relation which it bears to the question of a material increase in the flow of Hudson River by storage, a series of measurements of the flow of the feeder was undertaken early in October, 1895.

Arrangements having been made with the division superintendent to maintain a uniform feed for several days before the measurements began, as well as during the days when they were actually being made, and points established for verifying the uniformity of the flow during the time of the measurements, a series of accurate sections was then made at points both above and below the leakage, and a large number of current-meter readings taken from a footbridge thrown temporarily across the feeder at each section. The results so obtained are as follows:

(1) On October 8, 1895, the flow in the feeder just below the guard lock at the feeder dam, above all serious leaks, was 383 cubic feet per second.

(2) On the same day the flow at change bridge No. 13, about one-half mile from the feeder dam, above all serious leaks, was 364 cubic feet per second.

(3) On October 9 and 10 the flow a short distance below all serious leaks was 213 cubic feet per second.

(4) On October 10 the flow about half a mile farther down was 191 cubic feet per second.

(5) On October 11 the flow just above the locks at Sandy Hill was 182 cubic feet per second.

(6) A section, also taken October 11, in Champlain Canal, a short distance north of where the feeder enters, shows that the amount of water passing to the north at that time was 74 cubic feet per second.

These measurements show that the loss between sections 1 and 5, which may be taken as including about all the losses from the feeder, is 201 cubic feet per second. The water delivered into Champlain Canal is, therefore, only about 47 per cent of the quantity entering the feeder at the guard lock. The measurements also show that of the 182 cubic feet per second actually delivered to Champlain Canal 74 cubic feet per second is diverted to the north, and 108 cubic feet per second, less the loss from evaporation, etc., is returned to the river at the Saratoga dam.

Since the foregoing measurements were made, the enlargement of Champlain Canal has been begun, and its effect, by tearing up the old bottom, will undoubtedly be to decrease considerably the supply of water for the next few years. Taking into account this decrease, as well as the larger losses from evaporation and absorption by vegetation during the summer months, we may place the demands for the

enlarged Champlain Canal during the months of canal navigation at the following approximate monthly means:

Water required for the enlarged Champlain Canal.

	Second-feet.
May	553
June	600
July	600
August	600
September	553
October	510
November	495

With the leakage of Glens Falls feeder done away with, the foregoing figures may be reduced about 200 cubic feet per second for each month. For the section of Champlain Canal from Northumberland to Cohoes we may assume the water supply of the enlarged canal at about 255 cubic feet per second in May, October, and November, and at about 280 to 290 cubic feet per second in June, July, August, and September.

MIDDLE DIVISION.

This division comprises that portion of Erie Canal lying between the east line of Oneida County and the east line of Wayne County, as well as Oswego Canal from Syracuse to Oswego, the Baldwinsville side cut, the Cayuga and Seneca Canal, Black River Canal, and other short stretches as indicated in detail below. The following are the lengths in miles of the several sections:

Mileage of the middle division of Erie Canal.

	Miles.
Erie Canal from east line of Oneida County to east line of Wayne County	97.02
Oswego Canal	87.78
Side cuts and slips at Salina	2.02
Slips at Liverpool	.25
Baldwinsville side cut	.59
Cayuga and Seneca Canal	22.99
Black River Canal	35.52
Old Oneida Lake Canal	1.05
Chenango slip	.05
Chemung Canal, original lake level	2.53
Total	199.80

Mileage of river improvements pertaining to the middle division of Erie Canal.

	Miles.
Black River	42.50
Onondaga outlet	.75
Oneida River	20
Seneca River towing path	5.83
Seneca River	Not used.
Ithaca inlet	2.05
Seneca outlet	.17
Total	71.30

Mileage of navigable feeders of the middle division of Erie Canal.

	Miles.
Limestone Creek feeder	0.83
Butternut Creek feeder	1.67
Camillus feeder	1.04
Delta feeder	1.40
Black River feeder	11.29
Total	16.23

The total length of canal, river improvement, and navigable feeders on the middle division is thus found to be 299.08 miles. The following feeders of the middle division are not navigable:

Mileage of unnavigable feeders of the middle division of Erie Canal.

	Miles.
Chenango Canal, summit level	5.31
Leland Pond feeder	.31
Madison Brook feeder	2.99
West Branch feeder	5.83
Bradleys Brook feeder	.67
Hatch Lake feeder	.23
Kings Brook feeder	1.87
Oriskany Creek feeder	.53
Mohawk feeder at Rome	.03
Oneida Creek feeder	2.91
Cowasselon Creek feeder	.40
Chittenango Creek feeder	.28
Cazenovia Lake outlet	.51
Tioughnioga River feeder	1.00
De Ruyter reservoir outlet	.12
Orville reeder	.55
Camillus feeder (unnavigable portion)	.65
Carpenter Brook feeder	.18
Skaneateles Creek feeder	.09
Putnam Brook feeder	.20
Centerport feeder	.18
Owasco Creek feeder	2.10
Lansing Kill feeder	1.80
Sugar River feeder	.14
Canachagala Lake outlet	.16
Total	29.04

Rome level, which is a summit level, extends from lock No. 46 to lock No. 47, a distance of 55.96 miles. The following is the estimated water supply of this level before the beginning of the enlargement now in progress.

ERIE CANAL AT SYRACUSE, NEW YORK.

Water supply of Rome level, Erie Canal.

	Second-feet.
Lelands Pond, Madison Brook reservoir, Eaton Brook reservoir, Bradley Brook reservoir, Hatch Lake, Kingsley Brook reservoir, and Oriskany Creek feed through the Chenango Canal, Oriskany Creek, and Oriskany Creek feeder into the Rome level, 6 miles west of lock No. 46	100
Mohawk River, Black River, Forestport Pond, Forestport reservoir, White Lake reservoir, Chub Lake, Sand Lake, First, Second, and Third Bisby lakes, Woodhull reservoir, Twin Lakes, South Branch reservoir, North Branch reservoir, and Canachagala Lake feed through the Rome feeder and Black River Canal into the Rome level at Rome, 14 miles west of lock No. 46	217
Oneida Creek enters canal through feeder 30 miles west of lock No. 46	17
Cowasselon Creek enters canal through feeder 31.5 miles west of lock No. 46	3
Cazenovia Lake reservoir, Erieville reservoir, and Chittenango Creek enter canal through Chittenango Creek feeder, 41.5 miles west of lock No. 46; average for navigation season about	47
De Ruyter reservoir enters canal through Limestone Creek (Fayetteville) feeder, 50 miles west of lock No. 46; average for the navigation season about	32
Limestone Creek (natural flow) also enters canal through Limestone Creek (Fayetteville) feeder, 50 miles west of lock No. 46	8
Jamesville reservoir enters canal through Orville feeder, 52 miles west of look No. 46; average for navigation season	11
Butternut Creek (natural flow) enters canal through Orville feeder, 52 miles west of lock No. 46	8
Total	443

Jordan level, which is also a summit level, extends from lock No. 50 to lock No. 51 and is 14.903 miles in length. The following feeders are tributary to this level:

Water supply of Jordan level, Erie Canal.

	Second-feet.
Otisco Lake reservoir fed through Camillus feeder into the canal, 4 miles west of lock No. 50	86
Ninemile Creek (natural flow) also fed into canal through Camillus feeder	13
Carpenter Brook feeder	3
Skaneateles feeder	146
Total	248

The following feeders deliver water into the Port Byron level, which extends from lock No. 51 to No. 52, a distance of 7.79 miles:

Water supply of Port Byron level, Erie Canal.

	Second-feet.
Putnam Brook feeder at Weedsport	3
Owasco feeder	69
Total	72

Oswego Canal receives about 167 cubic feet per second from Erie Canal at Syracuse. The balance of its water supply is derived from Seneca and Oneida rivers. The total amounts to about 1,400 cubic feet per second. Seneca and Cayuga Canal receives about 67 cubic feet per second from Erie Canal at Montezuma, and 300 cubic feet

per second from Seneca Lake, making a total of 367 cubic feet per second.

The approximate water supply of the middle division of Erie Canal at present may therefore be summarized as follows:

Water supply of the middle division of Erie Canal.

	Second-feet.
Frankfort and Rome level	443
Jordan level	249
Port Byron level	70
Total	762
Oswego Canal:	
Supply from Seneca River	900
From Oneida River	333
Total	1,233
Seneca and Cayuga Canal	300
Grand total	2,295

The present total water supply of middle division may thus be placed, approximately, at 2,295 second-feet.[1]

RESERVOIRS OF THE MIDDLE DIVISION.

As indicated in the preceding statement of the water supply of the middle division, this division has an extensive system of reservoirs, as, for instance, Owasco Lake, the original surface of which has been raised by a dam on the outlet about half a mile below the foot of the lake. Skaneateles and Otisco lakes have also been raised by similar constructions. Proceeding east, the next reservoir is the Jamesville, formed by a dam on Butternut Creek. De Ruyter reservoir is on the dividing ridge, at the extreme head waters of Limestone Creek, and supplied by a feeder from the head waters of Tioughnioga River, a tributary of Chenango River. On Chittenango Creek, the next stream east of Limestone Creek, we find Cazenovia Lake, controlled by a dam at its foot and Erieville reservoir on the extreme head waters.

On the head waters of Oriskany Creek and Chenango River there is an extensive reservoir system, originally constructed for the purpose of supplying the summit level of Chenango Canal, but which has been retained in use for the water supply of the middle division, the water therefrom being conducted to Erie Canal at Utica, through the old prism of Chenango Canal, retained as a feeder, or to Erie Canal at Oriskany, through the natural channel of Oriskany Creek and a short feeder at Oriskany village. The reservoirs on the head waters of Oriskany Creek are Madison Brook and Lelands Pond reservoirs; those on the head waters of Chenango Creek, and which are connected with the summit level of the old Chenango Canal by a feeder

[1] This is a very general statement, and to be taken in connection with a large amount of detailed information in the reports not specifically cited at this time.

several miles in length, are Eaton Brook, Hatch Lake, Bradley Brook, and Kingsley Brook reservoirs.

Reference may also be made to the reservoirs on Black River and its tributaries. These are: Woodhull, Bisby Lakes Nos. 1, 2, and 3, Sand Lake, Chub Lake, White Lake, Canachagala Lake, North Branch Lake, South Branch Lake, Twin Lakes, and Forestport and Stillwater reservoirs. The Bisby Lakes have been abandoned. The details of these reservoirs on Black River, as well as those of all other reservoirs thus far connected for the water supply of Erie Canal, may be obtained from the table on page 166.

WESTERN DIVISION.

The western division of Erie Canal includes the following:

Mileage of the western division of Erie Canal.

	Miles.
Erie Canal from the east line of Wayne County to Hamburg street, in the city of Buffalo	148.92
Five slips in the city of Buffalo, aggregate length	1.60
Genesee River feeder in the city of Rochester	2.25
Total	152.77

The unnavigable feeders of this division are:

Mileage of the unnavigable feeders of the western division, Erie Canal.

	Miles.
Tonawanda and Oak Orchard Creek	11.55
Prism of old Genesee Valley Canal, Cuba reservoir to Rockville	7.65
Prism of old Genesee Valley Canal, Scottsville to Rochester feeder dam	11.00
Total	30.20

The only reservoirs on the western division are the Oil Creek and Rockville reservoirs, originally constructed to feed the summit level of Genesee Valley Canal, and still retained as subsidiary feeders to Erie Canal, their waters being finally discharged into Genesee River and thence taken into the canal through Genesee River at Rochester. The main characteristics of Oil Creek and Rockville reservoirs may be obtained from the table on page 166.

The sources of water supply for the western division are: Lake Erie, at Buffalo; Tonawanda Creek, at Pendleton; Tonawanda and Oak Orchard creeks, at Medina; Allens Creek, through the prism of the old Genesee Valley Canal, from Scottsville to Rochester; the Genesee River at Rochester.[1]

[1] The foregoing statements as to length, water supply, and reservoirs of Erie Canal, while covering only a small amount of the total data, are still as much as can be given at this time. Full information may be obtained by reference either to the annual reports of the State engineer and surveyor from 1850 to 1896, inclusive, or of the superintendent of public works from 1878 to 1896, inclusive. Previous to 1878 the reports of the canal commissioners may also be consulted for a large amount of useful information.

Reservoirs for the water supply of Erie Canal.

Reservoir.	Date of completion.	Elevation.	Distance to canal.	Flow-line area.	Height of flow line.	Average area.	Average depth.	Capacity.	Original cost.	Cost per million cubic feet.
		Feet.	*Miles.*	*Acres.*	*Ft.*	*Acres.*	*Feet.*	*Cubic feet.*		
ROME LEVEL—ERIE CANAL		428								
Woodhull	1859	1,854	25.0	1,236	16	1,118	18.0	876,550,000	$24,089	$27.47
Bisby Lake, No. 1 *a*	1881	2,018	27.8	156	4					
Bisby Lake, No. 2	1881	2,018	27.0	204	4		3.5	40,000,000		
Bisby Lake, No. 3	1881	2,006	26.0	41	4					
Sand Lake	1872	1,808	24.0	344	18	306	15.0	199,879,822	5,505	27.71
Chubb Lake	1881	1,599	20.5	530	22	200	4.0	34,848,000	8,134	233.43
White Lake	1881		18.0	332	5	296	5.0	64,468,800	5,102	79.27
Canachagala Lake	1881		32.0	347	4	320	4.0	55,756,800	1,456	26.11
North Branch Lake	1857	1,821	25.5	423	28	277	28.0	337,851,360	34,637	102.22
South Branch Lake	1859	2,019	26.0	518	26	372	26.0	421,312,320	20,168	47.87
Twin Lakes	1881		22.0	212	6	175	8.0	60,984,000		
Forestport Pond	1853	1,124	10.5	160			2.0	13,921,920		
Forestport reservoir	1894	1,139	12.5	793	21	700	7.0	212,444,000		
BOONVILLE LEVEL—BLACK RIVER CANAL		1,121	25.0							
JORDAN LEVEL—ERIE CANAL		408								
Skaneateles Lake	1844	864	9.0	8,320			9.0	2,174,512,000	14,928	6.87
Otisco Lake	1860		12.0	2,200			10.0	784,000,000	43,753	55.81
PORT BYRON LEVEL—ERIE CANAL		403								
Owasco Lake	1866	704	12.0	680			5.0	1,481,040,000	36,296	25.59
ROCHESTER LEVEL—ERIE CANAL		508								
CUBA LEVEL—GENESEE VALLEY CANAL		1,489								
Oil Creek	1858		91.0	605	65	525	15.0	435,738,000	69,216	158.85
Rockville	1842		8.30			72	20.0	18,200,000	7,711	423.68
ROME LEVEL—ERIE CANAL		428								
Erieville	1850	1,577	20.0	340	46		21.5	318,424,000	36,837	115.68
Cazenovia Lake	1857	1,176	10.0	1,778			4.5	348,523,000	10,885	31.23
De Ruyter	1863	1,276	25.0	626			18.5	504,468,000	78,761	156.13
Jamesville	1874	585	6.0	252		240	16.0	170,000,000	150,000	882.35
Hatch Lake *b*	1836		30.0	134	15		10.0	58,370,400	4,464	76.47
Eaton Brook *b*	1836		38.0	254	60	244	50.0	553,212,000	28,059	50.72
Bradley Brook *b*	1836		35.0	134	30		25.0	145,926,000	16,159	110.73
Leland Pond *b*	1836		25.0	173	13	150	8.0	59,287,040	8,894	150.02
Madison Brook	1836	1,127	29.0	345	55	235	45.0	490,647,000	36,301	73.80
Kingsley Brook	1867		33.0	113			20.0	98,445,600	80,481	817.54

a Supply to canal through Forestport Pond and Black River Canal.
b Supply to canal through Oriskany Creek feeder.

SHIP-CANAL PROJECTS AND WATER SUPPLY.

By virtue of the geographic position of New York, with the Great Lakes on its western boundary and the Atlantic Ocean on its eastern, and with the commercial capital of the Western Continent as its chief city, all discussions of deep waterway projects from the Upper

Great Lakes to the seaboard are, necessarily, chiefly discussions of the water resources of New York. It is proper, therefore, that the several deep water projects now under discussion should be briefly noticed in a report of this character.

In February, 1895, Congress by a joint resolution authorized a preliminary inquiry concerning deep waterways between the Great Lakes and the ocean, and provided that the President should appoint three commissioners to make such inquiry. The President, under this resolution, appointed Prof. James B. Angell, of Ann Harbor, Michigan; John E. Russell, of Leicester, Massachusetts, and Lyman E. Cooley, of Chicago, Illinois. The report of the commission, as published in 1897, includes a large amount of valuable information in regard to a deep waterway from the Upper Great Lakes to the Atlantic seaboard. In regard to the State of New York, it has been pointed out by Mr. Cooley that nature has indicated two feasible routes for such a canal. The first of these is the Oswego-Mohawk-Hudson route, extending from Oswego through the valley of Oswego and Oneida rivers, and thence across the divide to the Mohawk, thence through Mohawk Valley to a point on the Hudson in the vicinity of Troy, and so on through Hudson River to tide water at New York. One objection to this route is the lockage over the summit between Lake Ontario and Mohawk Valley. Another objection is the absorption of a large quantity of water in central New York for the supply of the summit level of the canal, and which probably can be more effectively used in manufacturing; that is to say, the State of New York, by developing its manufacturing resources to their fullest extent, can realize more return from manufacturing than from the use of its inland waters for purposes of internal navigation of any kind whatever. It may be pointed out in passing that the Oswego-Mohawk-Hudson route would utilize the great natural highway which has been an easy passage to commerce from the early days of settlement on the Atlantic coast.

The second natural route through the State of New York is by way of St. Lawrence River to the head of Coteau Rapids, where the low-water level of Lake St. Francis is 153.5 feet above tide, or 68.5 feet above the low-water level of Lake Champlain. On this plan a canal would be constructed from Coteau Landing to the head of Lake Champlain, near Rouses Point, this section requiring cutting through a summit about 50 feet in height. Lake Champlain would then be utilized to Whitehall, from which point a canal would be cut through the valley leading from Whitehall to Hudson River at Fort Edward, the elevation of the water surface of the Hudson a few miles below Fort Edward being somewhat less than the low-water elevation of Lake Champlain. After reaching the Hudson the work would include the deepening of that stream to deep water, a few miles below Albany. Either of the foregoing projects would further include the construction of a ship canal connecting Lakes Erie and Ontario.

The advantage of the St. Lawrence-Champlain-Hudson over the Oswego-Mohawk-Hudson route is that the lockage would be all in one direction; that is, eastward-bound vessels would lock down all the way from Lake Erie to New York. Its disadvantages are increased length and the location of the canal connecting St. Lawrence River with Lake Champlain in Canadian territory. In regard to increased length, it is claimed that not much more time would be required in traversing it than would be consumed in locking over the Oswego-Mohawk summit.

As to the capacity of the proposed canal, the Deep Waterways Commission points out in its report that such a canal, if built, should be so carried out as to be adequate for vessels of the most economical type, not only for coasting or domestic trade but also for the foreign movement, so that commerce may be carried on directly between lake ports and other domestic and foreign ports without transshipment. Taking into account various other conditions, the commission believes that the requirements of the present demand a limiting draft in the proposed canal of 27 or 28 feet; hence, in concluding the general discussion, the commission recommends the securing of a channel of a navigable depth of not less than 28 feet.

The commission also says that, starting from the heads of Lakes Michigan and Superior, the most eligible route for a deep waterway is through the several Great Lakes and their intermediate channels and the proposed Niagara ship canal to Lake Ontario, and that the Canadian seaboard may then be reached from Lake Ontario by the way of St. Lawrence River, and the American seaboard reached from Lake Ontario by way of either the Oswego-Mohawk-Hudson route or the St. Lawrence-Champlain-Hudson route. The Deep Waterways Commission was not authorized to make any considerable expenditure for surveys, and hence the conclusions announced are to some degree tentative. In view of the uncertainty as to final cost, it is recommended that the alternative routes from Lake Ontario to the Hudson be subject to complete survey in order to obtain a full development of the governing economic considerations, as well as to determine their relative availability.

The commission also recommends a moderate control of the level of Lake Erie and of Niagara River above Tonawanda by dam, but leaves the practical details undetermined in the absence of a full understanding of the physical conditions.

The river and harbor act of June 3, 1896, directs the Secretary of War to cause to be made accurate examinations and estimates of the cost of constructing a ship canal by the most practicable route, wholly within the United States, from the Great Lakes to the navigable waters of Hudson River, of sufficient capacity to transport the tonnage of the lakes to the sea. Under the provisions of this act a report

was submitted by Maj. Thomas W. Symons, of the Corps of Engineers, dated June 23, 1897.[1]

Major Symons states that there are three possible routes for the ship canal, entirely within the territory of the United States, from the Great Lakes to the navigable waters of the Hudson, as follows:

(1) From Lake Erie via the upper Niagara River to the vicinity of Tonawanda or La Salle; thence by canal, with locks, either to the lower Niagara at or near Lewiston, or to some point on Lake Ontario; thence through Lake Ontario to Oswego; thence up Oswego and Oneida rivers to Oneida Lake, and through Oneida Lake; thence across the divide to Mohawk River, and down that river to the Hudson at Troy; thence down the Hudson. This he designates as the Oswego route. From Oswego to Hudson River it is, in effect, the Oswego-Mohawk-Hudson route, already described.

(2) To follow either the line of Erie Canal from Lake Erie to the Hudson, or this line so modified as to provide for a continuously descending canal from Lake Erie to the Hudson. This he designates as the Erie Canal route.

(3) This route coincides with the first from Lake Erie to Lake Ontario, but runs thence through Lake Ontario to St. Lawrence River and down said river to some point near Ogdensburg; it then crosses the State of New York to Lake Champlain and up that lake to Whitehall; and thence follows in general the route of the Champlain Canal to Hudson River at Troy. This route, however, Major Symons pronounces impracticable.

There is also discussed a fourth route—the St. Lawrence-Champlain—all of which, except a small portion, is within the United States. This route would be via Niagara Falls, Lake Ontario, the St. Lawrence, Caughnawaga, and Richelieu rivers, Lake Champlain, and the Hudson.

The opinion is expressed that the best route for the contemplated ship canal is that via Niagara River, Lake Ontario, Oswego and Oneida rivers, Oneida Lake, and Mohawk and Hudson rivers, and that to build such a canal by any of the possible routes mentioned would, at a rough estimate, cost $200,000,000, the exact figure depending very largely upon the action of the State of New York in regard to the State canals, feeders, reservoirs, etc.; and that to maintain the canal and to keep it in repair, including the maintenance of river channels, reservoirs, and feeders, would cost, at a rough estimate, $2,000,000 a year. The statement is made that a ship canal would be of no special military value, and that its construction is not worthy of being undertaken by the General Government because the probable benefits to be derived from it would not be commensurate with the cost.

Major Symons further expresses the opinion that Erie Canal, when enlarged under the present plans of the State of New York, may

[1] See Ann. Rept. Chief of Engineers for the fiscal year ending June 30, 1897.

give, if State restrictions are removed, commercial advantages practically equal to those to be derived from the proposed ship canal, and that if Erie Canal be further improved by enlargement to a size sufficient for 1,500-ton barges, making such alterations in alignment as to give a continuously descending canal all the way from Lake Erie to the Hudson, and canalizing Mohawk River, the improved canal, navigated by barges, would render practicable the transportation of freight between the East and the West at a lower rate than by a ship canal navigated by large lake or ocean vessels. The difficulty of navigating large vessels through long, shallow canals is the loss of time and the consequent great increase in the pro rata expense account, as compared with the actual amount transported between termini. Major Symons is also of opinion that the enlargement of Erie Canal on these lines is a project worthy of being undertaken by the General Government, because the benefits to be derived would be commensurate with the cost, which he estimates at approximately one-fourth that of a ship canal, or $50,000,000.

Space will not permit abstracting in detail these several interesting reports on ship canals across the State of New York. To understand the subject in all its bearings, reference must be made to the original reports.

The Oswego-Mohawk-Hudson route is discussed in a report by Albert J. Himes in the Report of the State Engineer and Surveyor for 1895.[1]

In this report Mr. Himes expresses the opinion that a sufficient water supply could not be obtained for a high summit level across the divide, and hence the canal must be cut from the level of Oneida Lake through to the corresponding level in Mohawk Valley. In this way he proposes to use Oneida Lake as a storage reservoir from which to discharge water both ways to Oswego and Mohawk rivers. By this plan the surface of Oneida Lake would be raised 10 feet, furnishing 1,100 second-feet continuously for seven months. Without going into detail, the writer can not but believe that the water supply estimated by Mr. Himes is not entirely adequate for the supply of such a canal as has been proposed. If such a canal is constructed, the experience gained in the last seventy-five years ought to teach the danger of small economies in designing the water supply. Experience shows that canal water supplies must be made ample, as otherwise a shortage will result sooner or later.

In a paper on an enlarged waterway between the Great Lakes and the Atlantic seaboard, published by William Pierson Judson, the water supply of the summit level of the Oswego-Mohawk-Hudson route is discussed at length. Mr. Judson considers that it would be entirely proper to take whatever deficiency there might be from the

[1] See report on the Enlarged canal via the Oswego route, by Albert J. Himes, resident engineer, Eastern division, New York State canals. In Ann. Rept. State Eng. and Surv. for the fiscal year ending September 30, 1895.

head waters of the Black River, reservoirs in addition to those now existing being constructed on the Beaver and Moose rivers, tributary to the Black, for the purpose of furnishing this water. He recognizes that the item of adequate water supply for such a canal is vital, and frankly states that if surveys and thorough investigations were to show that the demand for water for such a canal is beyond the capacity of the sources of supply, then the Oswego-Mohawk-Hudson route would be shown to be impracticable, although, as an alternative proposition, he states that it would be entirely practicable to supply the summit level of such a canal from Lake Erie. This, it is pointed out, can be accomplished by a feeder branch taken from the present Erie Canal near Macedon, 12 miles west of Newark, where Erie Canal is now 35 feet above the Rome level. The proposed feeder, instead of stepping down, as does the Erie Canal, can be swung off to the south on higher ground at the necessary elevation, passing along the south side of Clyde River and crossing Seneca River near the Cayuga Lake Outlet. Seneca River is narrowest here, and the feeder could be carried across it in an open trunk on a 40 to 50 foot trestle about 2 miles long. Such a feeder 8 feet in depth and 38 feet in bottom width would carry 1,000 cubic feet per second, or enough, according to Mr. Judson, to meet the assumed needs. On this point, however, the author differs; he can not but think that the summit-level supply as estimated by Mr. Judson at 1,000 cubic feet per second is much too small. Mr. Judson's discussion of the deep-waterway question is further open to criticism in that he does not adequately recognize the economic value of the New York water supplies for use in manufactures.

In a paper read before the American Society of Civil Engineers in 1884, Elnathan Sweet proposed a ship canal through to Lake Erie via present line of the Erie Canal, except that its alignment be rectified to follow the line of the feeder, as proposed by Mr. Judson. The difficulties of making a ship canal on this line are, however, so great that many engineers have considered it absolutely out of the question.[1]

A canal on the Oswego-Mohawk-Hudson route 28 to 30 feet in depth, with corresponding surface and bottom dimensions, will probably absorb all available water of central New York, as well as a considerable portion of Black River. The water powers on Mohawk River at Cohoes will necessarily be made subservient to the exigencies of such a canal, although Mr. Judson, in the paper already referred to, has pointed out how valuable these water powers would be for seven or eight months of the year to the manufacturing cities of the Mohawk Valley. Under this head we may, however, inquire as to how the water power for only seven months of the year would be of any special

[1] See Radical enlargement of the artificial waterway between the Lakes and Hudson River, by Elnathan Sweet: Trans. Am. Soc. Civil Eng., Vol. XIV, pp. 37-139.

value to the city of Cohoes, where, owing to the kind of manufacturing, continuous power three hundred and ten days in the year is required. Cohoes had a population in 1890 of 22,509, and is stated to have grown considerably since, so that in 1897 the population is probably in excess of 25,000. This great development is a result of wise management of the water power, without which there is no reason to suppose that the area on which the city stands would have any greater value than that of the surrounding farming region. A proposition to interfere seriously with the water power at Cohoes can only be looked on by the author as most extraordinary. Indeed, not the least extraordinary feature of the present agitation for ship canals across the State of New York is the entire lack of appreciation—so far as the discussion indicates—of the value to the State of New York of its inland waters.

Aside from the report of Major Symons, the discussion has thus far apparently proceeded on the supposition that the taking of inland waters for navigation purposes was a matter on a par with the taking of agricultural lands for right of way, the economic value of the water for power purposes and the resulting effect on the internal development of the State having thus far been almost entirely ignored.

What the people of the State of New York need to consider first of all is whether the inland waters are not now worth more for manufacturing than they can possibly be worth for navigation purposes. If after investigation it is shown that the water will produce greater income to the people of the State in manufacturing than it will in operating such a canal, then from mere commercial considerations the people ought not to consent to the construction of such a canal. Without having the data at hand for a full discussion, the author, after giving the matter careful consideration, is of opinion that the State of New York can not afford to forego the possibility of developing its manufacturing interest in order to furnish water for the summit level of the proposed Oswego-Mohawk-Hudson deep-water canal. At any rate we should know just what results may be expected before embarking in the enterprise. If, however, after full investigation it appears that the canal water supply can be obtained and the manufacturing interests protected, no reasonable objection can be urged.

In order to justify the construction of the ship canal as a commercial proposition, the saving on the transportation of an estimated annual tonnage of 24,000,000 tons over the cost of its transportation by existing means and methods must, at least, equal the interest on the cost of the canal plus the annual cost of maintenance and operation. The first cost is taken at $200,000,000, with the maintenance at $2,000,000 per year. Assuming an interest charge of 3 per cent, the annual interest plus the maintenance becomes $8,000,000, which sum

represents the annual expense of the proposed ship canal connecting the Great Lakes with the Atlantic seaboard. As regards the State of New York, there should be added to this amount a sum representing the decrease in wealth in central New York due to the absorption of the inland waters of the State away from manufacturing interests in favor of navigation interests. As a rough estimate the author places such decrease at not less than $5,000,000 per year, although the decrease would probably be much greater than this, but in the absence of data for full discussion he places it at a conservative figure, which can not well be gainsaid. On the other hand, if the international St. Lawrence-Champlain-Hudson route were to be constructed, not only would this source of loss be entirely eliminated, but since that plan proposes to deliver water from St. Lawrence River into Lake Champlain, and thence by a through cut from Lake Champlain to Hudson River, there would be delivered into Hudson River a considerable quantity of water which would be available for power at Saratoga dam, Mechanicville, and Troy. This ship-canal project thus increases rather than decreases the productive capacity of the State. Moreover, it is probable that the St. Lawrence-Champlain-Hudson route can be constructed somewhat more cheaply than the Oswego-Mohawk-Hudson route.

Without wishing to present the foregoing as in any degree a final conclusion, the author can not but think that it is the broad view to take of the question. At any rate, this view presents a line of investigation which ought to be pursued to a conclusion before the final decision is made.

LOSS OF WATER FROM ARTIFICAL CHANNELS.

The large amount of canal construction in New York State has necessitated, in order to provide ample water supplies, the collection of considerable information as to the various sources of loss of water to which artificial channels are subject. Some of the more interesting results may be briefly referred to.

The original Erie Canal was constructed with the water surface 40 feet wide, the bottom width 28 feet, and the depth 4 feet. In 1824 measurements of the loss from filtration and evaporation were made by Mr. John B. Jervis on the eastern division and by Mr. David S. Bates on the western division. Mr. Jervis states that his measurements were made in the original Erie Canal, between the first locks below the village of Amsterdam and the aqueduct below Schenectady, a distance of 18 miles. This section was constructed mainly through an alluvial soil, containing a large portion of vegetable matter. In some places this soil was very leaky, owing probably to the decay of roots, although the greater portion retained water very well. There was a considerable quantity of gravel and slaty soils. He states that

the quantity of water lost in this 18-mile section was very uniform, and averaged 125 cubic feet per mile per minute.[1]

Mr. Bates states that his measurements in 1824 showed that a mile of new canal, such as Erie Canal then was between Brockport and Ninemile Creek, would require 1.7 cubic feet of water per mile per second in order to supply the losses from filtration, leakage, and evaporation.[2] The following are some of the details of Mr. Bates's measurements in 1824:

On 79 miles of canal and feeder, comprising 20 miles of canal from Rochester to Brockport, 57 miles from Rochester to Cayuga, and 2 miles of feeder, the supply was 8,000 cubic feet per minute, or 121.66 cubic feet per mile per minute. The months are not stated, although it may be inferred that these observations are averages of the navigation season.

Mr. Bates further states that in August, 1824, he found a total use for the 20 miles from Rochester to Brockport of 2,100 cubic feet per minute, equal to 105 cubic feet per mile per minute. This section of the original Erie Canal was considered to be entirely free from leakage at the structures, and the measured losses are therefore taken as those due only to percolation, absorption, and evaporation.[3]

In August, 1839, Henry Tracy and S. Talcott, acting under instructions from W. H. Talcott, resident engineer of the fourth division of Genesee Valley Canal, made a series of observations along the line of Chenango Canal, with a view of determining the evaporation, filtration, and leakage at the mechanical structures, and whatever else might be useful in the designing of the water supply of the summit level of Genesee Valley Canal.

For the purposes of the measurements they selected a portion of the canal extending from the north end of the summit level to Erie Canal, 22 miles in length, on which the total supply on August 31 was found to be 39 cubic feet per second. The leakage and waste at aqueducts, waste weirs, and at lock No. 1 at the northern end, were found to be 15 cubic feet per second, thus leaving the evaporation and filtration on 22 miles at 24 cubic feet per second, equivalent to 1.09 cubic feet per mile per second. It may be observed, however, that a measurement made at the end of August would probably not show a maximum of either evaporation or absorption by vegetation. Estimating these elements at the maximum, we may assume from 1.33 to 1.67 cubic feet per mile per second as a more reliable quantity than the 1.09 cubic feet per mile per second here actually observed.

[1] Report of John B. Jervis to the canal commissioners, on the Chenango Canal. Ann. Rept. Canal Com. (1834). Ass. Doc. No. 55, p. 54.

[2] Report of David S. Bates to the canal commissioners, on the Chenango Canal (1830). Ass. Doc. No. 47, p. 31.

[3] See report of F. C. Mills in relation to the Genesee Valley Canal (1840). Ass. Doc. No. 26, p. 26. See also report of W. H. Talcott in the same document. These two reports contain a summary of all that had been done in the way of measurements of the various losses now under discussion up to that time, as well as a number of references to foreign data.

Messrs. Tracy and Talcott also measured the leakage and waste at the various mechanical structures, etc., which were as follows: Leakage at structures, 220 cubic feet per minute; waste at waste weirs, 204 cubic feet per minute; leakage at lock No. 1, at the north end of the section, 479 cubic feet per minute. This amount, Mr. Talcott remarks, was so much greater than at any other lock on the canal as to induce the belief that the gates were not properly closed at the time of measurement. At lock No. 69 on the same canal, the leakage was 382 cubic feet per minute from an 8-foot lift.

Mr. Talcott's report is very able, and presents forcibly all the data at hand at that time. It may be said that the data which he gave fixed the following quantities as fairly covering the various losses to which artificial waterways of the dimensions of the original canals of this State are subject:[1]

(1) Loss by filtration, absorption, and evaporation, 100.0 cubic feet per mile per minute. With retentive soils this could be reduced to from 60 to 70 cubic feet per mile per minute. Mr. Talcott fixed on 66 cubic feet per mile per minute for Genesee Valley Canal, which was largely built through heavy soils, but this was subsequently found too small.

(2) Leakage at mechanical structures; for locks of 11 feet lift, 500 cubic feet per minute; for leakage and waste at each waste weir, 30 cubic feet per minute; for a wooden-trunk aqueduct, an amount depending on the length of the structure, but as an average, 0.35 of a cubic foot for each linear foot of trunk may be taken.

In response to a resolution of the canal commissioners of April 12, 1841, Mr. O. W. Childs, then chief engineer of Erie Canal, prepared a report on the water supply of the western division with reference to the enlargement then in progress.[2] In this paper Mr. Childs gives the results of measurements made by himself in 1841 of losses from filtration, absorption, evaporation, and leakage on the original Erie Canal between Wayneport, in Wayne County, and Pit Lock, which corresponded to lock 53, near Clyde, of the present canal. He also gave the result of measurements made by Alfred Barrett between Pittsford and Lockport.

Mr. Childs's measurements were for a section of the canal 36.02 miles in length. On the Palmyra level, for a distance of 8.34 miles, where the soil is open and porous the measurements showed a loss of 1.81 cubic feet per mile per second. On the Clyde level with a more retentive soil the losses from filtration, absorption, and evaporation were, for a distance of 27.68 miles, only 0.59 cubic feet per mile per second. The entire loss, including leakage, was, for the whole distance, 1.40 cubic feet per mile per second. These measurements were made for

[1] The quantities here given apply to canals 40 feet by 28 and 4 feet deep, and with locks 90 feet in length and 15 feet in width and 8 to 10 feet lift.

[2] See Supply of water required for the canal between Lockport and the Seneca River, by O. W. Childs: Ann. Rept. Canal Com. (1848). Ass. Doc. No. 16, pp. 141-175.

a term of thirty-three days, from July 30 to August 31, inclusive. Measurements were also made in June, early in July, and in the folowing October, from which the conclusion was derived that demands were greater and the supply less for the time during which the foregoing observations were taken than during any other portion of the season.

Mr. Barrett's measurements were made at various points on the original canal between Pittsford and Lockport, and repeated each day from July 17 to September 30, inclusive. They showed an average loss for the whole period of 73.0 cubic feet per mile per minute. Assuming the same ratio of loss between Pittsford and Wayneport, there resulted, for the entire distance of 122 miles from Lockport to Pit Lock, an average loss of 67 cubic feet per mile per minute. Mr. Childs states that an addition to the foregoing quantity should be made as an allowance for springs and several small streams entering the canal which could not be measured. Making such additions he concludes that 1.42 cubic feet per mile per second should be taken as the total quantity consumed on the 122 miles of canal under consideration, which is equivalent to a total of 173 cubic feet per second. It is stated in the original reports that the supply of water was ample for all the purposes of navigation during these measurements.

Comparing Mr. Childs's measurements of 1841 with those made by Messrs. Jervis and Bates in 1824, one point of great practical utility is strongly brought out, namely, as to the excess of loss of water in new canals over those some time in use; thus Mr. Bates found in 1824, on the same reach of canal as was measured by Mr. Childs in 1841, a total loss of from 1.68 to 1.75 cubic feet per mile per second. It may be assumed that the springs and streams allowed for by Mr. Childs were delivering into the canal in 1824 the same as in 1841, at least 0.17 to 0.25 cubic feet per mile per second. We have, then, as the total supply in 1824 from 1.92 to 2.00 cubic feet per mile per second. Adopting the latter figure as a maximum to compare with Mr. Childs's figure of 1.42 cubic feet per mile per second, as found in 1841, the conclusion is reached that the decrease in the loss by filtration—due presumably to the gradual silting up of the bottom—is something like 0.75 cubic feet per mile per second.

This conclusion may be applied to the conditions of the Erie Canal enlargement now in progress, in which it is proposed to excavate 1 foot from the bottom of many of the levels. The effect of this will be to remove the silt accumulations of many years, thus placing the bottom of the canal, as regards porousness and consequent percolation and filtration loss, in the same condition as when constructed. This consideration alone indicates the necessity of making the water supply of the enlarged canal liberal in order to answer the demands of the first few years while the bottom is again attaining a fixed condition.

Under this head it may be remarked that the experience of seventy-five years in the operation of the New York State canals has thoroughly shown the futility of any attempt at excessive economy in water supply. In the absence of systematic information as to yield of streams, the general tendency has been to overrate the summer flow, with the result of shortage frequently at points where the supply was believed to be ample. The chief sources of such shortage may be enumerated as follows:

(1) The great variation in the yield of drainage areas from year to year, by reason of differences in the rainfall, humidity, and temperature.

(2) The cutting off of forests, which has increased somewhat the spring-flood flows and decreased the summer flow.

(3) The systematic drainage of large areas, which has also tended to increase the flood flows and decrease the summer flows.

(4) The growth of aquatic plants on long levels and the formation of sand bars in the canal, which have tended to decrease the amount passing.

Among minor sources of loss, evaporation and absorption by growing plants may be mentioned, both of which vary somewhat in different years, although neither can be considered a serious source of loss. A number of other measurements of the losses from the original Erie Canal are recorded in the reports, but the foregoing are sufficient for present purposes.[1]

A study of all the measurements in detail shows that in an artificial channel of the dimensions of the original Erie Canal, and constructed on the American system, there should be provided at least 80 to 100 cubic feet per mile per minute, exclusive of water for filling and for lockages.

Using the data of the measurements of 1841, Mr. Childs arrived at the water supply of the enlarged canal of that day in the following manner: It was assumed that the loss by filtration through the bottom and sides of the canal would be as the square root of the pressure or depth of the water, and as the area of the surface pressed. Proceeding on this assumption, he computed the quantity required to supply the losses from filtration, leakage, and evaporation (in the enlarged canal, 1840 to 1860), at 3.17 cubic feet per mile per second. This figure was subsequently substantially adopted for the entire enlarged canal, and, with the exception of a few special cases, is still in use.

Adding the amount required for lockages at lock 53, Mr. Childs placed the entire supply for the western division, from Lockport to the east end, at 3.48 cubic feet per mile per second, or at a total of 424 cubic feet per second for 122 miles of canal.

The canal enlargement now in progress contemplates an increase in

[1] Ass. Doc. (1840), No. 96, p. 26; also Ass. Doc. (1842), No. 24, p. 37.

depth from 7 to 9 feet. Taking into account the results of the measurements on the original Erie Canal, as well as those made by Mr. Childs on the enlarged canal of 1840 to 1860, it has been concluded that the proper figure for water supply on the western division, to which the studies thus far specially refer, should be taken at from 4.17 to 4.5 cubic feet per mile per second.[1]

As to the use of water for lockage, leakage of gates, drawing and swelling of boats, and for turbine water wheels to operate gate-lifting machinery, reference may be made to the Annual Report of the State Engineer and Surveyor for 1889, where data covering these different points may be found.

Ordinarily, the flow of a natural drainage channel increases farther down the stream. The outlet of Skaneateles Lake, however, appears to present an opposite example—that is to say, there is less water flowing at the mouth of the stream than at its head. This statement is derived from a report on the water supply of the middle division of Erie Canal, made in 1862,[2] according to which measurements were made by Mr. S. H. Sweet of the flow through the natural channel of the Skaneateles Outlet, 10 miles in length, discharging into the Erie Canal at Jordan. Mr. Sweet's measurements, which were continued through the dry season of 1859 and the entire season of navigation, apparently indicated a loss of water of more than 3,000 cubic feet per minute in this natural channel. The detail, however, is lacking, and probably before accepting this as a fact the measurements made in 1859 should be verified.

USE AND VALUE OF WATER POWER.

WATER POWER OF ERIE CANAL.

When Erie Canal was first constructed the policy was adopted of leasing the so-called surplus waters for power purposes. Under the terms of the act of 1825, leases were made during 1826 and subsequent years to a number of persons at Black Rock, Lockport, and other localities.

POWER AT BLACK ROCK.

The granting of these leases and the resultant development of large manufacturing interests at several points have raised certain economic questions which will now be briefly discussed. The water power at Black Rock, for which several leases were granted, may be first mentioned. This power is created by the difference in level between the water in Erie Canal and Black Rock Harbor and that in Niagara River outside the harbor wall, this difference of water level

[1] The foregoing statements in regard to measurements of water supply of Erie Canal are abstracted from a report on the water supply of the western division of the Erie Canal, by the author, and are to be found in Appendix I to the Ann. Rept. of the State Eng. and Surv. for the fiscal year ending September 30, 1896.

[2] See Ann. Rept. of State Eng. and Surv. for the fiscal year ending September 30, 1862, pp. 402, 403.

amounting to from 4 feet to 4.5 feet. As measured in the spring of 1896, at a point near the ship lock, it was about 4 feet. According to the report of the assembly committee of 1870, as referred to in the footnote, there were formerly ten mills in operation at Black Rock, using 2,744 second-feet of water. The power developed by these mills, and all operating at full capacity, is estimated at not exceeding 520 horsepower. Owing to the decline of the milling business in New York State a number of these mills have passed out of existence.

The four mills still in existence require about 1,200 cubic feet of water per second to operate them at the full capacity of the wheels now in place.

The use of water by the Black Rock mills has always been a detriment to navigation. When all were running the amount of water actually drawn through the canal and harbor for their supply, and for the supply of the canal to the east of Buffalo, was fully 3,300 cubic feet per second.[1]

When all the Black Rock mills were in operation the great draft of water so obstructed the navigation that the legislature finally authorized the construction of a division wall in Black River Harbor, by which it was expected that the water supply for the mills would be entirely taken from the harbor, leaving the channel of the canal pretty nearly free for the purposes of navigation; but after the greater part of the wall was completed it was ascertained that because of the silting of the upper harbor with sewage mud, as well as drifting sand from the lake, there would be difficulty in obtaining the full supply for the mills through the harbor, without extensive dredging. The division wall was, therefore, never completed, two gaps, amounting, in the aggregate, to several hundred feet, having been left below Terry street. There was thus an expenditure of about $350,000 for the benefit of the milling interests which is entirely without effect for lack of completion. Under the present conditions, however, of entire decline of the Black Rock milling interests, there is, of course, no reason why the wall should be completed, and the matter is discussed here at all merely for the purpose of bringing out clearly the struggle between the navigation interests and the manufacturing interests, which has been in progress in New York State for the last seventy-five years.

POWER AT LOCKPORT.

At Lockport the construction of the Erie Canal through the mountain ridge created a fall of 58 feet at a single point, and since the use of water for lockage purposes is only a small part of the whole flow. The balance required to feed the canal to the east of Lockport is necessarily discharged around the locks into the lower canal by means of

[1] The assembly committee of 1870 give the following figures as then applicable: Lower Black Rock mills, 1,887 second-feet; upper Black Rock mills, 858 second-feet; for supply of canal, 583 second-feet; total, 3,328 second-feet.

sluiceways. Under the provisions of the laws of 1825, a public auction was held in the village of Lockport, in the fall of that year, and the right to use this surplus water sold to Messrs. Richard Kennedy and James H. Hatch, whose successors at the present day constitute the Lockport Hydraulic Power Company.

Lockport has usually been considered more purely a result of the canal development than any other point in western New York, for the reason that while nearly all other towns in the region had some growth before the Erie Canal was located, it was only in 1821, after the present location for the canal had been definitely decided on, that the nucleus of a village was formed here by the contractors and their workmen employed on the canal. In 1820 there was no frame house or barn within 5 miles of Lockport, and there were less than 600 acres of cleared land in the 4 square miles, of which the city of Lockport is now the center. Moreover, there are no natural advantages which would have naturally led to the growth of an important town at this point. The water supply of the region is so deficient that even to this day the city takes its public supply from Erie Canal, which is grossly polluted with sewage from the city of Buffalo. It may be considered, therefore, that the city of Lockport owes its existence entirely to the creation by Erie Canal of a large water power at this point.

When once started, however, under the impulse of the canal development, Lockport grew rapidly until, in 1829, with a population of 3,000, it was incorporated as a village, and in 1865 as a city. The population in 1890 was 16,038; in 1897 it is estimated at over 17,000.

The total investment in manufacturing plants at Lockport dependent on the Erie Canal water supply amounts to $2,531,000. The total number of establishments is 33, employing 1,880 operatives. The total power now in use on Erie Canal proper is 2,625 net horsepower.

A short distance to the east of the foot of the locks a small stream known as the West Branch of Eighteenmile Creek crosses under the canal. This stream, although having a drainage area of only 1 or 2 square miles to the south of the canal, has cut a deep valley with rapid fall for a considerable distance to the north of the canal. In order to provide for discharging the surplus waters from the canal, an overflow into Eighteenmile Creek was constructed at an early day. A mill was also permitted to take water from the lower level and discharge its tail-water into the creek. Finally the Jackson Lumber Company was permitted to construct a sluiceway on the towpath side, through which it drew for many years about 600 second-feet, and which was all discharged into Eighteenmile Creek. Complaints having frequently been made that boats were drawn against this sluice on the towpath side, the superintendent of public works, in 1892, granted a formal permit to the Jackson Lumber Company to construct a sluice and subway under the canal bottom, by which this water is now drawn from the berme side. Under this permit a substantial

masonry sluice was constructed in 1893. In the meantime the Jackson Lumber Company has gone out of existence, and this water power has passed into the hands of the Traders' Paper Company, which now occupies the site with its pulp mill No. 1.

West Branch of Eighteenmile Creek descends about 175 feet within the limits of the city of Lockport, of which 148 feet have been utilized for power during recent years.

The following are the companies now using power on this creek and the horsepower used by each:

Power utilized on West Branch of Eighteenmile Creek.

	Horsepower.
Traders' Paper Company	1,060
Lockport Paper Company	230
Niagara Paper Company	115
Westerman and Company	320
Cascade Pulp Company	925
Cowles Smelting Company	1,185
Total	3,835

The output of the establishments on West Branch of Eighteenmile Creek is about $2,000,000 a year; but this sum includes the output of the Indurated Fibre Company, which, while operating by steam power, depends largely for a supply of pulp on the Cascade Pulp Company. In any case, the figures show the magnitude of the manufacturing interests which have been fostered in the valley of West Branch of Eighteenmile Creek, by discharging into that stream about 300 second-feet of water from the Erie Canal.

With 2,625 net horsepower in use on the canal proper, and 3,835 on West Branch of Eighteenmile Creek, the total actually in use at Lockport, and dependent on Erie Canal for its water supply, is 6,460 net horsepower.

No statements as to the value of the annual product of the manufacturing establishments on the raceways of the Lockport Hydraulic Power Company have been given. It is therefore impossible to state accurately the value of the total annual product at Lockport. As several of the establishments there are very extensive, including the Holly Manufacturing Company, it may be assumed that the annual output of this portion of the Lockport manufactories has a value, at least, of $1,000,000; hence we reach a total value of the annual product for the whole city of about $3,000,000.

The annual rental paid to the State, under the terms of the original lease, is only $200. At first sight it appears that there is here a most marked case of what could only be termed blundering on the part of State officials, although on analyzing the matter it is found that this extreme view is hardly correct. In the first place it must be remem-

bered that this lease was granted not only by authority of an act of legislature, but was only granted after a public auction had been held, at which Messrs. Kennedy and Hatch were the highest bidders. As already shown, had not the special conditions created by Erie Canal existed at Lockport, there would, in all probability, have been no thriving city at that point, but the area on which Lockport now stands would have been farming land, with no more value than now attaches to farming lands in the adjoining township of Lockport.

In order to show the results of this lease, at $200 a year, a study has been made of the growth of Lockport from the year 1865, when Lockport became a city, to 1896. It appears, for instance, that the valuation of the city has increased from less than $3,000,000 to over $6,700,000, and that the total State tax collected up to and including the year 1896 has amounted to over half a million dollars. If this had remained as a small farming community the State tax would probably not have been more than 3 per cent of this amount. Using this tax return as a basis, it has been computed that there has been an actual increase of wealth to the people of the State by the existence of Lockport of over one and a half million dollars, not including in this the actual increased value of the city itself. The conclusion is drawn that the benefit to the State at large has been very great on account of this expenditure for internal improvement, irrespective of questions of navigation.

POWER AT MEDINA.

The Oak Orchard feeder and the water power at Medina present somewhat different points for consideration from those at Lockport.

About 1820 the canal commissioners caused a cut-off channel to be constructed through Tonawanda swamp between Tonawanda and Oak Orchard creeks, whereby the early summer flow of Tonawanda Creek is diverted into Oak Orchard Creek. Oak Orchard Creek passes under the Erie Canal at Medina, and the original feeder channel at that place was an artificial channel leading from a dam thrown across the creek and entering the canal near West Branch of Oak Orchard Creek at Medina. At some period subsequent to 1823 a race way was constructed by private parties leading from a second dam higher than the feeder dam and conducting water into the central part of the village, where, after it is used, it is finally allowed to pass into the canal. During the enlargement of 1836 to 1862 the water-surface level of the canal at Medina was raised, and inasmuch as this change necessitated raising the feeder dam somewhat, it was finally concluded to discontinue the feeder and depend entirely on the race way for such supply as the canal might receive at this point.

Oak Orchard feeder has been considered as furnishing about 27 cubic feet of water per second to the canal, although measurements made in 1850 show about 37 cubic feet per second. Since then the clearing up of forests and the drainage of Oak Orchard and Tona-

wanda swamps have tended to reduce materially the low-water flow until it is probably less than 27 cubic feet per second. Moreover, for the future, the dry-weather yield from this drainage area may be expected to be somewhat less than in the past, because of the deepening of the channel of Oak Orchard Creek and of the crosscut authorized by the laws of 1893. The act provided for deepening the channel of Oak Orchard Creek from a point 2½ miles below where Tonawanda Creek enters the Oak Orchard and for the cleaning, improving, widening, and deepening of the channel of East Branch of Oak Orchard Creek. This work has been done as a sanitary measure, and its effect will probably be to run the water out of the swamps more rapidly in the spring, thus materially decreasing the dry-weather flow.[1]

According to a statement furnished by Mr. A. L. Sweet, president of the Business Men's Association of Medina, the number of operatives employed in 1896 in manufacturing enterprises dependent on water power at Medina was 515; the amount of capital invested in establishments actually in operation was $371,000, while the value of the annual product of the same establishments was $575,000. These figures do not include the Medina Falls flouring mill, which was idle at the time these statements were made.

The total developed water power at Medina, on the race way and on the Oak Orchard Creek, is estimated at 827 horsepower, which includes the wheels at Medina Falls flouring mill. Deducting these wheels, amounting to 338 horsepower, the total actually in use in 1896 is 489 horsepower. The use of water at the establishments on the creek varies from 110 cubic feet per second to 49 cubic feet per second, the former quantity being due to the Medina Falls flouring mill, where the head is 33 feet. Relative to the fine power at Medina Falls, it may be stated that it is improbable, considering the amount of power available at this location, that it will remain unutilized for any great length of time. The trouble at Medina Falls flouring mill is the same as that affecting the large flour mills at Black Rock and other places in New York—the competition of cheap grain and transportation from Western mills.

Without going into the historical part of the subject, it may be said that the mill owners at Medina claim that by reason of the granting of a right of way for the cut-off between Tonawanda and Oak Orchard creeks, and the gift of 100,000 acres of land to the canal fund by their original grantor, the Holland Land Company—a part of the consideration for which was an improvement of the water power of Oak Orchard Creek—they have an equitable right to the use of the water of the feeder. If, therefore, the effect of the drainage authorized by the laws of 1893 has been to decrease the low-water flow of

[1] For extended account of Oak Orchard Creek and its relations to the feeder, see Report on the drainage of the Oak Orchard and vicinity streams, in the Fourth Ann. Rept. of the State Board of Health (1883), pp. 43-116.

Oak Orchard Creek, it is maintained that the mill owners are entitled to enough water from the canal to make good the deficiency.

There are a number of other points on the Erie Canal where water powers have been fostered under the provisions of the laws of 1825, but lack of space precludes discussion of that phase of the subject.

SELLING PRICE OF WATER POWER.

The principal places in New York State at which hydraulic developments have thus far been made for the purpose of selling power are Oswego, Cohoes, Lockport, and Niagara Falls. At Oswego the power on the east side of the river is owned by the Oswego Canal Company, the development being by a canal 4,000 feet long, with an average surface width of 60 feet and a depth of 6 feet. The water from this canal is dropped into Oswego River at the level of Lake Ontario. The working head is from 18 to 20 feet, although with high water in the canal and low water in Lake Ontario, the working head becomes somewhat greater.

The State controls the first right to the flow of Oswego River in order to maintain slack-water navigation in the pool above the dam at the head of the Oswego Canal Company's race way, all water not needed for canal purposes being equally divided between the Oswego Canal Company's race on the east side and the Varick Canal on the west side. The Oswego Canal Company gives a 999-year lease of water, but without land for location of buildings. A water right on this canal is called a run, meaning, probably, the amount of water required to drive a run of stone, a run of water being taken at 11.75 second-feet which, under the ordinary working head of 20 feet, will, at 75 per cent efficiency, produce 20 horsepower. There are assumed to be 32 first-class runs, the rental for which is $350 a year for each run. At this price the cost of a horsepower a year, with 75 per cent efficiency, becomes $17.48, or the cost of a gross horsepower a year becomes $13.11. There are also 32 second-class runs, of which the rental varies from $250 to $300 a year for each run. Further, there are surplus runs which are rented at a little over one-half of the rental charged for first-class runs. In case of a shortage of water the surplus runs are shut down successively, beginning with the most recent leases; after this the second-class runs share equally with one another in reduction; and finally, in case of extreme shortage, the first-class runs are similarly cut down.

The Varick Canal on the west side of the river controls one-half of all the water not needed for navigation purposes, the same as the Oswego Canal Company's canal on the east side. In order that the water may be divided equally between these two canals both have the same aggregate waterway at the head gates, and by gages on both sides, which are examined whenever necessary, it can be seen whether one canal is drawn below the other, and the gates changed accord-

ingly. On this canal there are recognized 50 first-class runs, 17 second-class, and an unlimited number of third-class. For first-class runs the rental is from $250 to $300 per annum; for second and third class it ranges from $125 to $150. By a decree of the supreme court, dated August 21, 1875, a run of water on the Varick Canal ranges between 28 cubic feet per second, under a head of 12 feet, and 25 cubic feet per second, under a head of 13 feet. The actual working head is, however, ordinarily only about 10 feet, so that on the foregoing basis a run of water may be taken as 33.3 cubic feet per second. At the price of first-class runs of from $250 to 300, and with 75 per cent efficiency, the cost per horsepower per annum varies from $8.80 to $10.56, a run on the Varick Canal being equal to 33.3 cubic feet per second on 10 feet head, an amount of water which yields 37.9 horsepower under that head.

As to the difference in cost of water on these two canals at Oswego, it may be pointed out that the Oswego Canal Company's race has a substantial advantage over the Varick race, in that it extends to the harbor, enabling vessels to come directly alongside of the mills. Moreover, the division of water rights is such that a first-class run of water can always be depended on along the Oswego Canal Company's race, but can not on Varick Canal.[1]

At Cohoes we have the great power development built up by The Cohoes Company, which has, by careful management of the water power, built up at this place a fine manufacturing city of 25,000 inhabitants. Lack of space will not permit description of this development in detail.

The Cohoes Company not only owns all of the hydraulic canals, but also the land adjoining the canals. It gives to manufacturers a perpetual lease of land and water, the entire property leased remaining subject to a rental of $200 per year per mill power. On this basis the land is regarded as donated and the rental applies only to the water power. Formerly, the standard for measuring water was 100 square inches, to be measured through an aperture in a thin plate 50 inches wide, 2 inches deep, and under a head of 3 feet from the surface of the water to the center of the aperture; but in 1859 a series of measurements were carefully made under the direction of the late James B. Francis, using an old canal lock as a measuring chamber. These measurements showed that the old standard corresponded to about 5.9 cubic feet of water per second. As a result 6.0 cubic feet of water per second, under 20 feet head, was taken as a new standard constituting a mill power. On this basis a mill power is equivalent to 13.63 gross horsepower, which, at $200 per mill power per annum, costs $14.67 per gross horsepower per annum. At 75 per cent efficiency the annual rental for water for net hrrsepower becomes $19.57. In

[1] For additional detail of the water power at Oswego, see Report of Water Power of the United States, Tenth Census, Vol. I, pp. 24-27.

regard to just what is paid for by the annual rental, both at Oswego and Cohoes, it may be remarked that the foregoing prices are for water in the race way, the company maintaining the dams, head works, and main race ways, the lessee taking the water at the face of the race way and maintaining his own head gates, flumes, bulkheads, wheels, and any other appliances necessary for utilizing the water in the production of power.

The water power at Lockport, owned by the Lockport Hydraulic Company, is formed by the drop of the surplus water of the Erie Canal through a distance of 58 feet. A run of water at Lockport does not appear to be very well defined, but the rental charge ranges from $12.50 to $16.67 per effective horsepower. So far as known to the author, just what constitutes an effective horsepower has not been defined.

At Niagara Falls the rental price of undeveloped hydraulic power has been fixed at from $8 to $10 per gross horsepower per annum, the party renting the power taking the water at the face of the head race and making its own connection with the discharge tunnel. Electric power by a two-phase alternating current as it comes from the generator is sold in blocks of 2,000 or 3,000 horsepower, at $20 per net horsepower per annum, the purchasers furnishing transformers, motors, and all other electric appliances. In small blocks the price has been fixed somewhat higher.

A small amount of power has also been sold at different times at Rochester, but since the power at this place is nearly all held by manufacturers who use it at first hand, nothing like a fixed price has been made at Rochester. Generally, power rented has been in small quantities and in connection with floor space, the rental price being really for floor space with small power furnished. Reckoning on this basis, small powers have frequently been rented at Rochester at as high a price as $100 per horsepower per year, this being for power on the shaft, all expenses of maintaining wheels, transmission shafts, etc., being borne by the owner.

The electric companies at Rochester furnish electric power in small blocks at 3 cents per electric horsepower per hour, which, on the basis of ten hours a day and three hundred and ten days a year, becomes $93 per electric horsepower per annum.

STATE OWNERSHIP OF INLAND WATERS.

Without going into a detailed discussion as to State ownership of inland waters in New York, attention may be called to a few of the more essential facts. The absolute ownership by the State of the beds and banks and water flowing in the Hudson and Mohawk rivers has been confirmed by repeated decisions of the highest courts of the State. By reason of the peculiar circumstances of the early settlement of the country the English common-law rule applies to all the

streams of the State except the Hudson and Mohawk, from which it results that all other inland streams are owned to the thread of the stream by the abutting proprietors.

Owing to a confusion of ideas—largely on the part of citizens appointed to the position of canal appraisers, where they exercised to some extent judicial functions—there arose in the early days a broad claim of State ownership to inland waters tributary to the Erie canal. The claim was, however, finally decided in the negative. This condition has, in the case of Genesee River, worked great injustice to the riparian owners, in that under a claim of temporary diversion and an assumed right of permanent appropriation by a statutory enactment declaring the stream a public highway no adequate damages have ever been paid for the diversion actually made from the stream for many years.

A similar lack of appreciation of the real relations of the State to individual citizens in regard to common rights in running streams has apparently led to the enunciation of a course of action on the part of canal officials which, to some extent, in effect confiscates private property.

In the case of Black River the State has extensively adopted the method of compensation in kind rather than compensation in money. In view of the large development of storage on Black River, under the provisions of chapter 181 of the laws of 1851, in excess of what is really required there actually to make good the diversion during the low-water season, and, further, by reason of the State's finally placing the management of the principal reservoirs there in the hands of a commission of owners and users of water power, as provided by chapter 168 of the laws of 1894, it may be assumed that as regards Black River, the State has adopted the policy of conservation of water power, such policy being in line with the best thought of the present day.

In the case of Skaneateles Lake there was for several years a struggle between the State and the city of Syracuse as to the right of that city to obtain the municipal water supply from Skaneateles Lake, the extraordinary feature of that controversy being the assumption on the part of the agents of the State that the municipalities of the State, even in the important matter of public water supply, had no rights which the State apparently was bound to respect.

It may be pointed out that the considerable diversity of law and policy, in regard to the rights of riparian owners thus shown to exist in the State of New York, can not operate other than to discourage the full development of the State's natural resources. What is greatly needed, therefore, in the State of New York is a consistent policy of some sort as between the State, the navigation, the manufacturing, and all other interests, in which each shall receive proper consideration. Thus far navigation interests have usually been placed first,

although it is clear that had there been a more thorough balance, the State as a whole would have been considerably in advance of its present position.

FUTURE USE OF WATER POWER IN NEW YORK.

In the foregoing pages we have seen that the Erie Canal was a development from the necessities of commerce, not only for the State of New York, but, as a means of connecting the Atlantic Ocean with the waters of the Great Lakes, for accelerating the industrial development of the Northwestern States. However, in the nineteenth century events move rapidly, and what was true of the Erie Canal thirty to fifty years ago is not necessarily true to-day. Railway systems have now developed to such completeness as to compete successfully with water transportation by a channel of the size of the Erie Canal. The Erie Canal, therefore, has no longer an indispensable place in our transportation system. Apparently it should either be radically enlarged, with entirely new methods of management, or else abandoned in favor of a ship canal along other routes.

During the period covered by the rise and decline of the Erie Canal as the important factor in through transportation between the East and a large portion of the West the economic conditions of the interior portion of New York have entirely changed. Cheap transportation, by way of Erie Canal and the Great Lakes, has led to a phenomenal development of agriculture on the broad plains of Minnesota and the Dakotas, where, by the use of modern agricultural machinery, grain can be raised at a profit at such prices as to drive the New York grain grower from the market. The cheap transportation afforded by the Erie Canal has, therefore, to a considerable degree, led to the passing of supremacy from the hands of the Eastern farmer, a loss which can only be regained by the development to the fullest extent of the manufacturing industries of New York, thus making a home market for farm products that can not be transported a long distance, such as garden truck and small fruits. The people of the State of New York can purchase the Western breadstuffs as cheaply as they can be produced at home, and this condition is likely to continue indefinitely.

The long supremacy of the navigation interests has moreover led to the incorporation in the law, jurisprudence, and public policy of this State of certain rules of action as to the right to use the water of inland streams, which have tended to discourage the full development of manufacturing interests which now appears desirable, although the author views with satisfaction the rapid change of public sentiment now taking place on these questions. That manufacturing industries by water power are rapidly increasing in the State is made sufficiently clear by the following statistics:

According to the United States censuses of 1870 and 1880 the total developed water power of the State of New York was, in 1870, 208,256

horsepower; in 1880, 219,348 horsepower; increase in the ten years, 11,092 horsepower. The increase in ten years of 11,092 horsepower is equivalent to an increase of 5.4 per cent. The United States census of 1890 did not include any statistics of water power, and it is impossible therefore to state definitely the horsepower in that year; still, taking into account the great increase shown by the special investigations on Hudson River in 1895, on Genesee River in 1896, and at Niagara Falls in 1897, and also considering the advances in paper making—a water-power industry—as well as the great development now taking place at Massena, the increase for the whole State from 1880 to 1900 may be estimated at about 120 to 140 per cent. On this basis there will probably be in use in New York State at the close of the nineteenth century a total water power of something like 500,000 gross horsepower. The manufacture of mechanical wood pulp alone consumes about 125,000 gross horsepower. These figures, while very suggestive as to the future, are nevertheless rendered more pertinent by considering that with full development of the water-storage possibilities of the State, as well as the possibilities of power development on Niagara and St. Lawrence rivers, we may hope ultimately to reach a water-power development in the State of New York something like the following:

Possible development of water power in New York.

	Gross horsepower.
Streams tributary to Lake Erie	3,000
Niagara River (in New York State)	350,000
Genesee River and tributaries	65,000
Oswego River and tributaries	40,000
Black River and tributaries	120,000
Other tributaries of Lake Ontario	10,000
St. Lawrence River	400,000
Oswegatchie, Grass, Racket, St. Regis, Salmon, Chateaugay, and other streams tributary to the St. Lawrence	150,000
Saranac, Ausable, Lake George Outlet, and other streams tributary to Lake Champlain	40,000
Hudson River and tributaries, not including Mohawk River	210,000
Mohawk River and tributaries	60,000
Streams tributary to Allegheny River	5,000
Streams tributary to Susquehanna River	25,000
Streams tributary to Delaware River	30,000
Water power of Erie Canal	10,000
Total	1,518,000

But 1,518,000 gross horsepower has an effective productive value in manufacturing of say $100 per horsepower per annum, or the inland waters of this State have an ultimate economic value, when fully developed, of at least $151,800,000 per annum. They may therefore be considered, in producing capacity, substantially equal to the entire agricultural product of the State in 1890, which, according to the United States census of that year, amounted to a total of $161,593,009.

Indeed, taking into account that agricultural values are continually depreciating, and water-power values appreciating, it is probable that ultimately, if New York State agriculture remains on the same basis as at present, the water-power values will considerably exceed the agricultural values. It is probable, however, if the manufacturing industries of this State are ever so far developed as to bring water power into use to the extent of 1,518,000 gross horsepower, that the local demand for agricultural products will have considerably changed the present downward tendency. As an off-hand figure, we may, therefore, place these two values, at some not very distant date, as equal, and aproximating about $200,000,000 per annum.

OBSTRUCTIVE EFFECT OF FRAZIL OR ANCHOR ICE.

A very serious difficulty in operating water powers on many of the more rapid streams of this State is that caused by the formation and agglomeration of frazil and anchor ice, and probably there is no subject in connection with water-power development which presents so many difficulties as this. So far as can be learned, nothing has been done in the State in the way of studying these phenomena, although the water powers on many New York streams are reported as subject to interruption nearly every year on account of the formation of frazil and anchor ice. The way to find a remedy is first to ascertain all that can be learned in regard to the difficulty to be overcome. From this point of view it is deemed proper to include herein a short account of studies of frazil and anchor ice made in the neighboring Dominion of Canada.

Under the direction of John Kennedy, chief engineer of the harbor commissioner's works at Montreal, very extensive studies of the formation of frazil and anchor ice have been made. The terms "frazil" and "anchor ice" have been used synonymously, and are apparently often understood as the French and English words for the same thing, but the following from the Report of the Montreal Flood Commission of 1890 will serve to define the difference. According to this report, frazil is formed over the whole unfrozen surface wherever there is sufficient current or wind agitation to prevent the formation of border ice; whereas the term anchor ice includes only such ice as is found attached to the bottom. Frazil is frequently misused by being made to include ice formed on the bottom, as well as throughout the mass and on the surface of a river, although properly it should be only applied to floating ice. The common theory has been that anchor ice first forms on the bottom, subsequently rising. The Montreal studies, however, show that this is hardly true. At times the whole mass of water from surface to bottom is filled with fine needles which actually form throughout the water mass itself.

As to the remedy, the studies are hardly complete enough to indicate the best course to pursue. As practical hints, it may be stated

that in locating dams on streams specially subject to this difficulty they should be placed with reference to as long a stretch of backwater and as great depth as possible, all the studies thus far made tending to show that the formation is most extensive in shallow, rapid-flowing water. Usually trouble from frazil and anchor ice extends through a period of a day or two; and at very important plants, where even a short interruption would be a serious matter, arrangements may be made for using steam at the head works for keeping the racks open. This plan has been successfully pursued at the waterworks intakes of several of the Great Lake cities. In the case of power plants, where much larger quantities of water are required and the stream flows with greater velocity, the amount of steam required may be found to be very large.[1]

WATER YIELD OF THE SAND AREAS OF LONG ISLAND.

Long Island is about 114 miles in length, with a varying width of from 10 to 20 miles. Its watershed line consists of a regular ridge of low hills running from New York Bay to the eastern extremity of the island. The highest points of this ridge are about 350 to 390 feet above sea level. This ridge, which is believed to be a part of the terminal moraine of the great glacier, consists mainly of compact drift and bowlders, running at times into clay and coarse gravel. The considerable number of small ponds along the ridge evidence the compactness of its surface material. The slopes and spurs of the central ridge run into Long Island Sound on the north, making an irregular shore line, broken into bays and low headlands. On the south side the slopes lose themselves in a grassy plain sloping gently toward the coast. In its widest part it is called the Hempstead Plains, and stretches for a distance of from 5 to 15 miles between the foot of the central ridge and the Atlantic shore, which is very regular in its outer beach line; but an inner and more irregular beach exists, formed by the shallow waters of Jamaica and Hempstead bays. The Atlantic shore does not anywhere touch the slope of the central ridge, but is separated from it by the wide gravelly plain just referred to.

Numerous small brooks originating on the south slopes of the central ridge cross the gravelly plain, delivering their waters to the Atlantic. On the largest of these brooks gristmills were established at an early date, with ponds of from 8 to 40 acres of water surface and from 5 to 9 feet depth of water.

The fall at these dams rarely exceeds 8 feet. The original municipal water supply of the city of Brooklyn, as constructed about 1856 to 1859, had its source in the Hempstead Plains, several of the large brooks flowing from the central ridge to the Atlantic being appropri-

[1] For reference to the literature of frazil and anchor ice see (1) Report of the Montreal Flood Commissioners of 1886; (2) Reports of the Harbor Commissioners of Montreal for the years 1885, 1887, and 1895; (3) Paper on Frazil ice and its nature, and the prevention of its actions in causing floods, by George H. Henshaw, Trans. Can. Soc. C. E., Vol. I, Part I, pp. 1-23; and (4) Paper on the Formation and agglomeration of frazil and anchor ice, by Howard T. Barnes, in Canadian Engineer, Vol. V (May, 1897).

ated for this purpose. A distributing reservoir was established on the central ridge at an elevation of 170 feet above tide, with the water of the brooks forced thereto by pumping. These brooks were all mainly fed by springs delivering directly into their ponds and channels. The length of these water courses from where the water was taken to the summer sources rarely exceeds 4 miles. In the original construction the waters of these ponds were conveyed by small branch conduits to a large main conduit extending from the most easterly pond or reservoir to the pump well at the engine house, which was located at the foot of the ridge on which the Ridgewood distributing reservoir was situated, not far from the east line of the city of Brooklyn. The main conduit was so located that the water flowed to the engine house by gravity. The following are the statistics of the six ponds originally taken for the Brooklyn city supply, the minimum deliveries here given being as ascertained by measurements during the months of September and October, 1856 and 1857. The figures represent the natural delivery of each stream at its lowest stage of water, and do not include any encroachment upon the stored water which each pond retained, when full.

Area of surface, minimum flow, and elevation of overflow of six ponds originally taken for the Brooklyn city supply.

Pond.	Area of surface (acres).	Minimum flow (cubic feet in 24 hours).	Elevation of overflow above tide (feet).
Jamaica	40.00	419,315	7.90
Brookfield	8.75	265,038	15.40
Clear Stream	1.07	100,448	11.50
Valley Stream	17.78	325,291	12.80
Rockville	8.00	353,388	12.60
Hempstead	23.52	1,054,713	10.60

The same streams were measured in October and November, 1851, and the aggregate result then was 3,137,500 cubic feet. With the exception of Clear Stream, they were again measured in October, 1852, the result then being 2,606,300 cubic feet in 24 hours.

According to a survey made by Theodore Weston in the fall and winter of 1859, the drainage area of the streams originally taken for the municipal supply of Brooklyn was found to measure 46.8 square miles, but subsequent measurements have placed it at 49.9, which is the figure now used.[1]

As already stated, the drainage grounds lie mainly on the Hempstead Plains, although a small portion may be considered as lying on the southern slope of the central ridge. The ridge slopes are composed of clay and alluvial earth, with little power of retaining

[1] As to the difficulty of determining just what the drainage area of any one of these streams actually is, see I. M. De Varona's History and Description of the Brooklyn Waterworks, 1896.

water. Hempstead Plain, on the other hand, consists of a very uniform deposit of sand and gravel with occasional thin veins of clay; hence Hempstead Plain is largely receptive and retentive of water. The sand and gravel on this plain serves two purposes as regards the rainfall sinking into it: (1) It retains the water, only gradually delivering it to the surface in the valleys of the brooks or on or near the seashore in the form of springs; (2) it filters and purifies it, the gravel and sand performing the function of a natural filter bed. It is considered that but a small portion of the ground water of this gravel plain has been derived from the rainfall of any single year. The greater portion of it is considered to have collected during a series of years. Borings and open wells show that this ground water has a nearly uniform inclination toward the south shore of about 12 feet per mile.

Upon the low ridges lying between the several streams crossing Hempstead Plain the inclination of the ground water varies with the width of the ridge, and is steeper in these parts than on the main slope toward the sea, the resistance of the retaining material there being proportionately less. So long as the slope of the ground water is left undisturbed by pumping, as from a series of wells, the permanent slope of the ground water is determined by the resistance of the material through which it flows. As regards the minimum flow of the streams receiving these underground waters, the longer the time occupied by that portion of the rainfall which sinks into the ground in reaching the outlets the greater will be the minimum flow of the stream as compared with its total flow; on the other hand, the shorter the time the smaller the minimum flow. In the case of the Long Island streams the minimum flows are not very large, a fact which indicates that the permanent regimen of these streams is probably maintained by the accession of the absorbed rainfalls of several years. It follows that so long as the basins are not drawn upon very greatly in excess of their flowage capacity the permanency of Long Island ground water supplies is only moderately affected by variations in the yearly rainfall.[1]

The water supply of the city of Brooklyn has frequently been increased in order to meet the necessities of the constantly increasing population. Additional drainage areas have been taken, and open wells and driven-well systems have been constructed and additional streams and ponds appropriated. At present there are a number of deep open wells, each about 50 feet in diameter, and several driven-well stations. For details of the original conduits, ponds, and streams reference may be made to a description of the Brooklyn waterworks in Water Power of the United States, Tenth Census, 1880, Volume XVII, as well as to the histories of the Brooklyn waterworks.

[1] The foregoing statements relating to the water-yielding properties of the Long Island sands are mostly derived from Kirkwood's History of the Brooklyn Waterworks and Sewers, published in 1867. For a more recent, as well as more extended, discussion of the same subject see De Varona's History and Description of the Brooklyn Waterworks.

In a report on the future extension of the water supply of Brooklyn, by Mr. I. M. De Varona, engineer of the water supply, transmitted to the common council, January 31, 1896, tables are given of the total monthly and average daily quantities of water pumped into the Ridgewood reservoir for the years 1860 to 1895, inclusive.

The accompanying table has been condensed from this report, giving in calendar years the total rainfall upon the watershed and the per cent of this utilized by pumping at Ridgewood. The average yield utilized is also expressed in cubic feet per second per square mile of watershed. This was originally 49.9 square miles, but was increased in 1872, being in subsequent years 52.3 square miles until 1883, when it was increased to 64.6 square miles, and in 1885 to 65.4 square miles. Considerable additions were made in 1891, and from that time on the area is given as 154.1 square miles. In 1860 the rainfall was 37.65 inches, and the total amount of water pumped was equivalent to a depth of 1.44 inches on the watershed, or 3.82 per cent of the total rainfall. In 1896 the total rainfall was 38.82 inches. The amount of water pumped during that year would cover the watershed to a depth of 11 inches, this being over 28 per cent of the total rainfall. The average yield as obtained by pumping was 0.81 cubic foot per second per square mile of watershed.

Total annual rainfall, per cent utilized, and average yield per square mile of watershed of Brooklyn waterworks.

Year.	Rainfall in inches.	Per cent utilized.	Second-feet per square mile.	Year.	Rainfall in inches.	Per cent utilized.	Second-feet per square mile.
1860	37.65	3.82	0.11	1879	39.61	33.40	0.97
1861	45.65	3.92	0.13	1880	40.76	30.23	0.90
1862	38.02	5.73	0.16	1881	39.53	29.42	0.86
1863	32.76	8.39	0.20	1882	39.83	30.73	0.90
1864	32.00	10.53	0.25	1883	37.22	33.05	0.91
1865	46.14	8.39	0.28	1884	45.39	27.89	0.93
1866	51.68	8.88	0.34	1885	36.85	37.94	1.03
1867	54.61	9.39	0.38	1886	51.38	28.32	1.07
1868	38.58	17.29	0.49	1887	45.66	32.59	1.10
1869	43.13	17.20	0.55	1888	48.45	33.19	1.18
1870	39.25	19.82	0.57	1889	56.54	29.54	1.23
1871	51.26	15.78	0.60	1890	52.15	33.90	1.30
1872	39.75	23.47	0.67	1891	39.18	44.82	1.29
1873	47.99	20.88	0.74	1892	37.75	24.53	0.68
1874	45.83	21.49	0.73	1893	39.62	26.27	0.77
1875	40.90	26.89	0.81	1894	36.88	26.33	0.72
1876	41.77	27.08	0.83	1895	35.64	28.98	0.76
1877	40.18	30.29	0.90	1896	38.82	28.31	0.81
1878	48.66	25.15	0.90				

Generally the Brooklyn waterworks have not been so designed as to furnish records of the quantity drawn from these several different sources. There are also no records of the heights of the ground water at different points in the drainage area. If such were to be kept for a series of years, the records of the Brooklyn waterworks would possess a value not easily estimated. They would give a far more positive indication of the amount of water that can be drawn from such sandy areas than can now be gained from them. A few tests, however, of some of the driven-well plants have been made in the last few years.

At a test of the old driven-well plant at Spring Creek, made from October 22 to November 20, 1894, water was pumped at an average rate of 4,091,551 gallons in 24 hours. The elevation of the underside of the discharge valve of the pump was 12.3 feet above datum. On October 22, at the beginning of the tests, the average elevation of the water in the wells was 4 feet below datum. The quantity pumped in 24 hours, on October 22, was 4,488,275 gallons. On November 20, the date of the conclusion of the test, the elevation of water in wells was 7.7 feet below datum, and the quantity pumped on that day in 24 hours was 4,112,663 gallons. The total quantity pumped during the entire period from October 22 to November 20 was 122,746,525 gallons. The taking of this quantity of water from the wells resulted, therefore, in lowering the ground water a total of 3.7 feet.

A new driven-well plant at Watts Pond was subjected to a test of capacity extending continuously from January 3 to February 2, inclusive. In 1895 a rather extended series of tests were made of a number of the wells of the Brooklyn water supply in order to determine the yield as well as the extent of the underground supply. The following particulars of these tests have been derived from Mr. De Varona's report, as contained in the annual report of the commissioner of city works for the year 1895.[1]

The flowing wells at Jameco were tested from January 3 to 14, inclusive. During this period the wells were operated singly and in groups of 2, 3, and 4, in all possible combinations, and observations were taken to determine the elevation of the ground water. Upon completion of the tests a series of observations was taken, extending to January 30, to determine the normal water level. The results of these observations may be found in detail in De Varona's report. It was shown that the average yield from one well alone was only 1,000,000 gallons daily, decreasing pro rata up to a total yield of 3,500,000 gallons daily when four wells were in operation. The lowering of the ground water was approximately 5 feet when pumping 1,000,000 gallons, increasing up to approximately 10 feet when pumping at the full capacity developed of 3,500,000 gallons. In this connection it is stated that the water in these test wells is found to rise

[1] For a full account of the Brooklyn waterworks well systems see De Varona's History, etc.

and fall directly with the tide, thus rendering it difficult to state with accuracy the full effect of the pumping on the lowering of the water. To determine this point fully, De Varona states, would require a more prolonged series of observations than it was possible to make in 1895.

Another test was made at Jameco from December 9 to 20, 1895, inclusive. Between this date and the end of the previous tests an additional well had been sunk at Jameco to the depth of 160 feet. The average daily yield shown during the second test was, approximately, 1,000,000 gallons for a single well, with a proportionate increase for each well connected, the yield for five wells being, approximately, 5,000,000 gallons in 24 hours. The lowering of the water during those tests amounted to slightly over 14 feet at Jameco while pumping the 5,000,000 gallons daily from the five wells. The total amount of water pumped during the test was 61,239,555 gallons. The greatest lowering of the underground water level occurred at test well No. 8, where it amounted to 15.23 feet. At that time, when the water at Jameco was at its lowest level, the fall between test well No. 8 and test well No. 11 was 9.9 feet. The normal water level was not restored until twelve days after the tests had ceased.

The results obtained early in 1895 from the test made at Jameco of supplies from deep wells seemed to warrant further investigations as to the possibility of water from deep wells, and the report states that they have been carried on during the year. A series of test wells were driven, extending from the foot of the hill at Ridgewood reservoir to Forest Stream pumping station, each well being carried to a depth sufficient to determine the possibility of obtaining a deep supply from that point. The number of those wells sunk during that year was twelve, and the records of the strata passed through are given in Bulletin No. 138, referred to in the footnote.[1]

Returning to the table on page 194, it may be stated that the tributary drainage area in 1875, the first year for which statistics are given in the table, was 52.3 square miles. The drainage area remained at this figure until January, 1881, in which month, by the bringing of the Springfield pumping station into use, it was increased to 59.4 square miles. In the water year of 1875, with a total rainfall of 41.6 inches, the water utilized amounted to 10.78 inches, or to an average of 513,165 gallons per square mile per day, or to 0.79 of a cubic foot per square mile per second. In the water year of 1880, with a total rainfall of 40.04 inches, the water utilized amounted to 12.37 inches on the watershed, or to 587,568 gallons per square mile per day, or to 0.91 of a cubic foot per square mile per second. In 1881, with a rainfall of 41.52 inches, the total utilization of water amounted to 11.64 inches on the watershed, or to 554,473 gallons per square mile per day, or to 0.86 of a cubic foot per square mile per second. This drop in

[1] For the particulars of the geology of several of the Brooklyn waterworks wells, of which tests were made in 1895, see Artesian-well prospects in the Atlantic coastal plain region, by N. H. Darton: Bull. U. S. Geol. Survey No. 138, 1896, pp. 23-37.

the unit of utilization merely shows the effect of the increase in the area of the watershed.

The tributary watershed remained at 59.4 square miles until August, 1883, in which month the Spring Creek and Baisley's driven-well stations were started. From this date the tributary drainage area is taken at 64.6 square miles. Spring Creek and Baisley's stations marked the beginning of the Brooklyn driven-well system. In the water year of 1884, with a total rainfall of 43.44 inches, the utilization was 12.53 inches, amounting to 594,992 gallons per square mile per day, or to 0.92 of a cubic foot per square mile per second.

In May, 1885, the Forest Stream and Clear Stream driven-well stations were started, thereby increasing the tributary drainage area to 65.4 square miles. In the water year of 1886, with a total rainfall of 50.43 inches, the water utilized amounted to 14.40 inches, equivalent to 685,521 gallons per square mile per day, or to 1.06 cubic feet per square mile per second.

The drainage area remained 65.4 square miles until June, 1890, when it was increased to 65.6 square miles by the addition of the Jameco Park driven-well station. In the water year 1891, with a total rainfall of 40.34 inches, the water utilized amounted to 18.48 inches on the watershed, equivalent to 879,811 gallons per square mile per day, or to 1.35 cubic feet per square mile per second.

Large extensions of the works were made in 1890 and 1891, so that with the beginning of pumping at Millburn on December 17, 1891, the tributary drainage area may be considered as increased from 65.6 to 154.1 square miles, an increase of 88.5 square miles. In the calendar year 1892, with a rainfall of 37.75 inches, the water drawn from the original watershed of 65.6 square miles amounted to 16.81 inches on the watershed, equivalent to 800,191 gallons per square mile, or to 1.24 cubic feet per second per square mile. The water drawn from the new watershed of 88.5 square miles that year amounted to 3.67 inches on the watershed, equivalent to 174,776 gallons per square mile per day, or to 0.27 of a cubic foot per square mile per second. In 1895, with a total rainfall of 35.64 inches, the original watershed of 65.6 square miles yielded 12.62 inches on the watershed, equivalent to 600,723 gallons per square mile per day, or to 0.93 of a cubic foot per square mile per second. The new watershed of 88.5 square miles furnished in that year 8.64 inches on the watershed, equivalent to 411,558 gallons per square mile per day, or to 0.64 of a cubic foot per square mile per second.

Summarizing the information in regard to the water yield of the sand plains of Long Island, it may be stated that the available data indicate a large yield. The streams of eastern New York can not be relied upon in their natural condition to yield more than about 0.3 of a cubic foot per square mile per second, while with an ordinary development of storage the limit may be usually placed at from 0.7

to 0.8 of a cubic foot per square mile per second, or at any rate at not much exceeding 1 foot per square mile per second. The sand deposits of Long Island may, therefore, be considered as great natural reservoirs from which, with proper development, large water supplies may be drawn, the same as from reservoirs artificially created on the earth's surface, these natural underground reservoirs possessing the advantage of furnishing a filtered water of high purity.

INDEX TO PAPERS NOS. 24 AND 25.

Page.

Adirondack Plateau, water yield of 16-18
Allegheny Mountains, water yield of 16
Allegheny River, hydrography of 44
Anchor ice, obstruction from 14, 190-191
Ausable River, fall of 32
Battenkill River, hydrography of 40-41
  power of 41
Black River, hydrography of 29-30, 96-97
Black River Canal, cost and revenues of. 154-158
  length and capacity of 158
Black Rock, water power at 178-179
Brooklyn, water supply of 15, 43, 47, 191-195
Buffalo Creek, course of 24
Canadaway Creek, power of 24
Canals, construction of 145-150
  cost and revenues of 154-155
  improvement of 155-157
  transportation by 150-154
  water supply of 158-161, 164-166, 173-178
  See Ship canals.
Canaseraga Creek, course of 25
Catskill Mountains, water yield of 16
Cayuga and Seneca Canal, construction of 149
  cost and revenues of 154
Cayuga Lake, drainage area of 23
Champlain Canal, construction of 148-149
  cost and revenues of 154-157
  length and capacity of 157, 158
  water supply of 159-161
Chateaugay River, course of 30
Chemung Canal, construction of 149
  cost and revenues of 154-155
Chemung River, drainage area of 88
  floods in 12, 87-90
Chenango Canal, construction of 149
  cost and revenues of 154-155, 157-158
  length and capacity of 157-158, 161-165
  loss of water in 174-175
Chenango River, course of 45
Chicago drainage canal, water diverted through 62
Clyde River, drainage area of 28
Cohocton River, course of 45
Cohoes, water power at 35, 185-186
Crooked Lake Canal, construction of 149
  cost and revenues of 154-155
Croton River, hydrography of ... 12, 33, 82-86, 98
  storage on 86-87
Deforestation, effects of 11, 12, 14, 16-17
Delaware River, hydrography of 46-47
Des Plaines River, hydrography of. 54-55, 64-65

Page.

East Canada Creek, hydrography of 36-37
  power of 37-38
Eaton Brook, hydrography of 67, 68
Erie Canal, construction of 13, 147-150
  cost and revenues of 154, 157
  improvement of 155-156, 169-171
  length and capacity of 157, 158, 161-165
  transportation on 13-14, 150-154
  water power of 178-184
  water supply of 158-161, 164-166, 173-178
Fish Creek, fall of 36
Fish Creek, power of 41
Floods, occurrence of 12, 72-73, 87
Forests, influence of 16-18
Frazil, obstruction from 14, 190-191
Fredonia, stream measurements near 95
Genesee River, flood on 112-113
  hydrography of .. 11, 25-27, 57, 58, 70-75, 90-92
  power of 109, 123-125
  storage on 12, 109-125
  tributaries of 25-26
Genesee Valley Canal, cost and revenues of 154-155
Grass River, course of 30
Great Lakes, discharge of 58
  drainage area of 48
  precipitation on drainage area of .. 49-53, 58
Hemlock Lake, hydrography of. 12, 75-77, 92-93
Honeoye Creek, power of 26
Hoosic River, hydrography of 40
  power of 40
  storage on 40
Hudson River, commerce of 144-145
  hydrography of 33-34, 79-82, 97-98
  logging on 14
  precipitation on drainage area of 133
  storage on 12, 125-134
  tributaries of 33-43
Jameco, wells at 195-196
Kayaderosseras Creek, power of 41
Lake Champlain, streams tributary to ... 31-33
Lake Erie, altitude of 59
Lake Ontario, drainage area of 65
Little Falls, water power at 35
Lockport, water power at 179-182, 186
Long Island, hydrography of .. 14-15, 47, 191-198
Low-water flow of streams 90-99
Lumber, transportation of 14
Madison Brook, hydrography of 67, 68, 69
Massena, power development at 12, 143-144
Mechanicville, stream measurements at. 81-82
Medina, water power at 182-184

Page.

Mohawk River, hydrography of 35, 97
tributaries of 35–40
Morris Run, discharge of 93–94
Mount Morris, proposed reservoir at 110, 113–114, 117, 122–125
stream measurements at 58, 72–73, 91
Muskingum River, hydrography of 55–57
Neversink Creek, course of 46
Newell, F. H., letters of transmittal by .. 7, 107
Niagara Falls, power development at 12, 135–143, 186
Niagara River, hydrography of 11, 24–25, 48, 59–63
power development on 12, 135–143
Oatka Creek, hydrography of 69–70, 90
Oneida River, drainage area of 29
Oriskany Creek, course of 40
Oswegatchie River, course of 30
Oswego, water power at 184–185
Oswego Canal, construction of 149
cost and revenues of 154, 157
length and capacity of 157
Oswego River, hydrography of 27–29, 96
power of 29
Owasco Lake, drainage area of 28
Ownership of water 10, 14–15, 186–188
Paper, manufacture of 14
Pepacton River, course of 46
Portage, proposed reservoir at 114–125
stream measurements at 119–121
Precipitation, amount of 19–21
Price of water power 184–186
Raquette River, course of 30
Rochester, stream measurements at 72, 76–77, 91, 119
water power at 186
Rome, water supply of 35

Page.

Sacundaga River, hydrography of 42
storage on 128, 131
St. Lawrence River, hydrography of 65–66
power development on 12, 143–144
tributaries of 24–31
St. Regis River, course of 30
Saranac River, fall of 32
Sauquoit Creek, course of 40
Schoharie Creek, hydrography of 35–36
Schroon River, hydrography of 43
storage on 129
Seneca Lock Navigation Company, operations of 147
Seneca River, drainage area of 28
Ship canals, proposed routes for 166–173
Skaneateles Lake, hydrography of 77–78, 96
Spruce Creek, fall of 37
Storage reservoirs, advantages of 12, 111–112, 132–134
canals supplied by 164–166
capacity and cost of 116–117, 130–131
sites for 109–111, 113–125
Susquehanna River, hydrography of 44–46
Syracuse, stream measurements at 77–78
Temperature, variations in 18–19
Tioga River, course of 45
Tonawanda Creek, course of 24
Topography, character of 16–18, 21–23
Upper Mississippi reservoirs, discharge of 53–54
Warsaw, stream measurements at 93–94
West Branch of Canadaway Creek, discharge of 94–95
West Canada Creek, hydrography of 38–39
power of 39
Western Inland Lock Navigation Company, operations of 146

○

55TH CONGRESS, 3d Session. } HOUSE OF REPRESENTATIVES. { DOCUMENT No. 283.

DEPARTMENT OF THE INTERIOR

WATER-SUPPLY

AND

IRRIGATION PAPERS

OF THE

UNITED STATES GEOLOGICAL SURVEY

No. 26

WELLS OF SOUTHERN INDIANA.—LEVERETT

WASHINGTON
GOVERNMENT PRINTING OFFICE
1899

UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

WELLS OF SOUTHERN INDIANA

(CONTINUATION OF WATER-SUPPLY AND IRRIGATION PAPER NO. 21)

BY

FRANK LEVERETT

WASHINGTON
GOVERNMENT PRINTING OFFICE
1899

CONTENTS.

	Page.
Detailed discussion of wells	7
Randolph County	7
Delaware County	9
Madison County	10
Hamilton County	12
Boone County	13
Montgomery County	18
Fountain County	19
Vermilion County	20
Parke County	21
Putnam County	24
Hendricks County	25
Marion County	26
Hancock County	29
Henry County	29
Wayne County	31
Union County	33
Fayette County	34
Rush County	35
Shelby County	37
Johnson County	40
Morgan County	42
Owen County	43
Clay County	44
Vigo County	46
Franklin County	48
Decatur County	49
Bartholomew County	51
Jackson County	53
Scott County	55
Limestone district of southeastern Indiana	56
Knobstone belt of southern Indiana	59
Lower Carboniferous limestone of southern Indiana	60
Conglomerate sandstone of southern Indiana	60
Coal Measures basin of southwestern Indiana	61
Index	63

WELLS OF SOUTHERN INDIANA.[1]

By FRANK LEVERETT.

DETAILED DISCUSSION OF WELLS.

RANDOLPH COUNTY.

General statement.—Randolph County is situated near the middle of the eastern boundary of the State, with Winchester as its county seat. It has an area of 460 square miles.

This county has the distinction of being the most elevated one in the State. Only a small portion of its surface, along the Mississinewa and White rivers, in the northwestern and western parts, falls below the 1,000-foot contour. Several sections in the southeastern part have knolls and ridges rising above the 1,200-foot contour. The highest of these probably reaches 1,250 feet.

The highest land, found in the southern tier of townships, is occupied by a strong morainic belt, having a breadth of 5 or 6 miles and carrying sharp knolls and ridges 30 to 50 feet in height. Between this morainic belt and White River there is a gently undulating plain several miles in width. Immediately north of White River is a small moraine—the Union City ridge—scarcely a mile in average width, which enters the State at Union City and passes westward entirely across the county. This is a gently undulating ridge 25 to 50 feet in height. From this moraine northward to the Mississinewa River there is a gently undulating plain about 6 miles in width. Immediately north of the Mississinewa River is the Mississinewa moraine, which extends slightly into Randolph County.

[1] The present paper is a continuation of Water-Supply and Irrigation Paper No. 21, on "Wells of Northern Indiana," the division of the whole into two papers being rendered necessary by a statutory provision which limits the size of a single paper in this series to 100 pages.

The drift of this county is composed largely of a compact blue till, though in its deeper portions considerable sand is encountered. The thickness ranges from a thin coating up to fully 300 feet. Outcrops of rock occur along the Mississinewa, in the vicinity of Ridgeville, and on White River, near the west line of the county. With these exceptions the drift forms a continuous sheet, and probably has an average thickness of fully 150 feet. Twenty borings in the vicinity of Winchester, where the drift is scarcely so thick as in the southern portion of the county, show an average of 136 feet and a range from 70 to 334 feet.

Individual wells.—Along the Mississinewa moraine, on the north border of the county, several wells show a depth of 90 to 100 feet before entering rock. The drift is mainly a blue till.

At Ridgeville wells penetrate 30 or 40 feet of drift. A few are obtained without entering rock, but the best supply is to be found in the limestone. Many wells are obtained at a depth of only 40 feet.

On the plain between the Mississinewa moraine and the Union City ridge wells are usually obtained at less than 40 feet, and are mainly through till.

The drift in the vicinity of Union City ranges from 60 feet to fully 200 feet. Ordinary wells at Union City are obtained at a depth of about 35 feet in gravel beneath the blue till. The waterworks wells are estimated to yield about 1,500,000 gallons each per day. Two wells supply the city.

At Winchester the dug wells are often obtained at a depth of but 10 or 20 feet, and water is usually struck at 7 to 10 feet. Such wells being liable to contamination, deeper ones have been sunk, which obtain water near the top of the limestone at about 100 feet.

The deepest drift yet discovered in Randolph County was found in two wells about 1½ miles west and northwest from Winchester. In one well rock was struck at 331 feet; in the other at 334 feet. The upper portion of the drift at these wells is till, but the greater part is sand containing water.

Two water wells a short distance south from Winchester—one at Frank Moorman's, the other at Fountain Park Cemetery—do not reach rock at 205 and 210 feet, respectively. One boring in the east part of Winchester does not reach rock at 160 feet. Aside from this, the wells within the city limits of Winchester all enter rock at less than 150 feet, and one at 80 feet.

At Farmland, in the western part of the county, the drift in two gas wells is 58 and 60 feet, mainly till. Water wells are obtained at about 25 feet.

At the village of Parker, also in the western part of the county, water wells usually are obtained at 20 to 60 feet in thin gravel beds between sheets of till. A boring at the grist mill, however, extends to

the rock at 97 feet, and is mainly through till. A gas-well boring in Parker struck rock at 80 feet.

At the village of Windsor, on White River, south from Parker, the drift is mainly sand and gravel, and a gas-well boring shows its depth to be 107 feet.

At Losantville, on the moraine in the southwestern part of the county, the gas boring penetrates 240 feet of drift, some of it gravel, but mainly blue till. Water wells are obtained in that vicinity at 20 to 40 feet, with an occasional tubular well 60 or 80 feet in depth.

At the village of Lynn, in the south part of the county, a gas boring penetrates 117 feet of drift, of which the upper 50 feet is till and the remainder sand and gravel. Another boring in Lynn strikes rock at 124 feet, and its section is similar to the preceding.

The wells on the moraine in southern Randolph County, near the State line, usually obtain water at 20 to 30 feet, occasionally at 50 to 60 feet, in beds of gravel, between sheets of till.

DELAWARE COUNTY.

General statement.—Delaware County is situated in the eastern part of the State, immediately west of Randolph County. It has an area of 400 square miles, and Muncie, its county seat, is situated near its geographic center. The northeastern corner is crossed by the Mississinewa moraine, the eastern part is traversed by the Union City ridge, and the southeast corner is occupied by a strong moraine, the continuation westward of the one noted in southern Randolph County. There are several sharp gravelly knolls in the vicinity of Muncie and an esker of considerable prominence east of Royerton. These moraines and other knolls and ridges are confined to the eastern half of the county. The western half is a gently undulating plain.

The strong moraine in the southeast corner of the county is composed largely of a gravelly drift, but aside from this and the gravelly knolls and the esker above noted the drift of the county is mainly till. Over the greater part rock is usually struck at depths of 50 feet or less, but it is probable that on the moraine in the southeastern corner its thickness may exceed 200 feet. Many gas wells in the vicinity of Muncie enter rock at less than 20 feet, and rock is exposed extensively along the Mississinewa and White rivers in this county. Even if allowance be made for the existence of deep valleys, such as are encountered near Winchester, the thickness of the drift can scarcely exceed 100 feet. It is much less than in the neighboring counties on the north, east, and south, but is similar to the shallow drift of southwestern Grant County and northern Madison County, situated on the northwest and west.

Wells are ordinarily obtained at depths of 20 or 30 feet, either in

gravelly deposits near the base of the drift or in the upper part of the limestone. So far as the writer is aware, there are few if any water wells in the county whose depth exceeds 60 feet.

Individual wells.—At Selma, on the Union City ridge, in the east part of the county, the gas boring penetrates 92 feet of drift, as follows:

	Feet.
1. Yellow till	12
2. Sand with water	8
3. Blue till	12
4. Sand and gravel, becoming coarse near bottom	60
Total	92

At Daleville the drift is 85 feet, but wells are obtained in sand below till at 12 to 16 feet.

Near Wheeling, in the northern part of the county, wells in some cases reach a depth of 35 or 40 feet without entering rock. At Muncie, and also at Shideler and Eaton, wells ordinarily enter rock at 15 or 20 feet.

The waterworks at Muncie obtain their supply from several flowing wells drilled into rock. Three 8-inch wells are estimated to have a combined daily discharge of 50,000 barrels.[1]

MADISON COUNTY.

General statement.—Madison County is situated in the east-central part of the State, immediately west of Delaware, with Anderson as its county seat. It has an area of 450 square miles. The entire county is a gently undulating till plain, across which the drainage lines pass in a westward or southwestward course in narrow channels seldom cut to depths of more than 75 or 100 feet below its surface. The eastern border of the county rises slightly above 900 feet, and the western is fully 800 feet.

Throughout the entire county rock is frequently encountered at depths of 50 feet or less, but occasional borings have shown the existence of valleys deeply filled with drift, which are now completely obscured. The drift is largely a compact till, but affords a sufficient amount of water-bearing gravel and sand to supply the majority of the wells.

Individual wells.—At Summitville, in the northern part of the county, a gas-well boring penetrates 110 feet of drift, of which the upper 15 feet is till and the remainder gravel. Wells are usually obtained in this gravel soon after reaching the bottom of the till. On low ground in the west part of the village the wells pass immediately into the gravel below the surface soil or muck.

A gas well north of Summitville, near the Grant County line, penetrates 70 feet of drift, largely till.

[1] Manual of American Waterworks.

At Alexandria wells are usually obtained in the rock at a depth of about 60 feet. From this depth water rises about 30 feet. The drift at two gas borings in this village is reported to be 22 feet in depth:

	Feet.
1. Gravel	6
2. Blue till	16
Total	22

West from Alexandria the dug wells are ordinarily obtained in the drift at 15 to 20 feet. Tubular wells are somewhat deeper.

At Elwood wells enter rock at depths of about 40 feet, and some obtain water at 75 to 150 feet. In such wells the water usually rises nearly to the level of the bottom of the drift. The waterworks supply is obtained from a well 150 feet in depth and 8 inches in diameter. This well is estimated to yield nearly 20,000 barrels per day. An analysis of the water is given elsewhere.[1]

Several gas borings at Elwood show the drift to range from 40 feet or less up to 108 feet. One well having 56 feet of drift penetrates—

	Feet.
1. Till	15
2. Sand	4
3. Blue till	25
4. Sand	12
Total	56

At Anderson, the county seat, the ordinary wells range in depth from 15 feet to 100 feet. A portion of the city is underlain by gravel, and there is danger of contamination in the shallower wells. In the east part of the city wells in gravel are 60 to 75 feet. In the south and west parts the wells penetrate till to a depth of 50 to 100 feet before obtaining a strong supply of water. The city waterworks obtain the supply from the White River, but the water is not considered suitable for domestic purposes, being used only for lawns and streets and in baths. Several fountains are maintained in the city by pumping water from a deep well in White River Valley, near the waterworks pumping station. It is forced to the fountains by a pump connected with the waterworks engine. This well is reported to have an inexhaustible supply, and is objectionable only because of the sulphureted hydrogen which its water contains.

The gas wells in Anderson have drift ranging in thickness from 16 feet to nearly 200 feet. At a well in the west part of the city, in White River valley, 194 feet of drift is penetrated. At the crossing of the Panhandle and the Cincinnati, Wabash and Michigan railways, on the bluff north of the river, 191 feet of drift was penetrated. A well three blocks southwest of the court-house penetrates 91 feet of drift,

[1] Eighteenth Ann. Rept. U. S. Geol. Survey, Part IV, p. 498.

entirely gravel. At the court-house the drift is 48 feet, and is entirely gravel. A well west of the crossing of the Bee Line and Panhandle railways penetrates 104 feet of drift, of which the upper 34 feet is sand and gravel, and the remainder blue till.

In several wells on the plain 2 or 3 miles southeast of Anderson, a bluish-black muck, resembling a soil and carrying considerable wood, is reported to occur at depths of 20 to 40 feet.

At Frankton, in Pipe Creek valley, about 6 miles northwest from Anderson, a gas boring penetrated 85 feet of drift.

At Huntsville and Pendleton, in the valley of Fall Creek, about 8 miles south of Anderson, rock outcrops occur, but the drift in some cases is 90 feet.

At Markleville, in the southeast corner of the county, a gas well penetrates 147 feet of drift. Water wells in that vicinity are obtained at 20 to 40 feet, and often encounter a blue mud, carrying wood.

HAMILTON COUNTY.

General statement.—Hamilton is the center county of the State, with Noblesville as its county seat, and has an area of 400 square miles. The White River valley traverses the southeastern part of the county. The only other streams of importance are Cicero Creek, which enters White River from the north, near Noblesville, and Fall Creek, which touches its southeastern corner. The eastern two-thirds of the county is nearly level and stands about 800 to 850 feet above tide. In the western third there is a gradual rise to a higher plain, 900 to 950 feet, which occupies much of Boone and Clinton counties. This rise is occasioned, not by greater elevation of the underlying rock, but by a thickening of the drift deposits. Indeed, the general rock surface lies lower in the western part of the county than in the central and eastern, as shown by numerous gas-well borings. The upper portion of the drift in this county is principally a compact till, but there are small areas bordering the valley of White River in which the till is replaced by gravel. There are also gravelly terraces along the stream. The deeper portions of the drift throughout the county appear to carry large amounts of gravel and sand.

Individual wells.—In the vicinity of Noblesville the drift has a known range from 33 feet to 186 feet, the shallowest drift being found about a half mile north of the court-house, in the valley of White River, and the deepest about 2 blocks north of the court-house, at the Evans well. In both wells it is mainly gravel. A well in the valley, 1½ miles north of the court-house, penetrates 176 feet of drift, mainly gravel, but having 40 feet of red clay at bottom. Several wells about 2 miles east of Noblesville also penetrate a gravelly drift and enter rock at about 80 feet. A well 1½ miles west of this city penetrates 98 feet of drift, mainly till.

The dug wells in the city of Noblesville obtain the first vein of water at about 20 feet, but a greater quantity and better quality is obtained at a depth of 65 or 75 feet. Wells are therefore often bored to that depth. The city waterworks contains an inexhaustible supply from such wells at a depth of 70 or 80 feet.

At Cicero, 6 miles north of Noblesville, two gas wells reach rock at 141 and 161 feet, and are mainly through till. A well 1 mile south of Cicero penetrates 270 feet of drift, largely sand and gravel, but with 60 feet of hard reddish till at the base.

At Fishers Station, 6 miles south of Noblesville, a gas well penetrates 110 feet of drift.

At Carmel the drift is only 96 feet, but at Westfield, about 5 miles west of Noblesville, one gas well strikes rock at 196 feet and another at 220 feet. The drift is mainly till in both wells. A well 3 miles southeast of Westfield penetrates—

1. Drift	95
2. Till	20
3. Sand and gravel	75
Total	190

At Eagletown, in the west part of the county, a gas-well boring penetrates 200 feet of drift:

	Feet.
1. Till	160
2. Sand and water	20
3. Red clay	20
Total	200

At Jolietville the drift is about 200 feet and mainly till.

At Sheridan a gas well penetrates 233 feet of drift:

	Feet.
1. Till	150
2. Sand and gravel, with water	40
3. Red clay, with white pebbles	43
Total	233

In the east part of the county, at Clarksville, a gas well enters rock at 16 feet, but one a mile north of the village penetrates 82 feet of drift, mainly till.

From the deep sections above given it should not be inferred that water wells are difficult to obtain, for throughout much of the county an abundance of water is found at convenient depths, wells seldom exceeding 40 feet.

BOONE COUNTY.

General statement.—Boone County is situated in the central portion of the State, immediately west of Hamilton, with Lebanon as its county seat. It has an area of 420 square miles. Its elevation is somewhat greater than the counties to the east or west, and the water parting between the Wabash and White rivers traverses its central

portion from north to south. The elevation of this divide is due not to the high altitude of rock strata, for gas borings have shown that the rock strata have a greater elevation on the slope toward the Wabash in western Boone County and in Montgomery County than along the divide. So far as known to the writer there are no outcrops of rock in the county. There is in the eastern and central part of this county, as in the counties to the east and north, a deposit of drift 250 to 300 feet or more in thickness. The surface of the county is almost entirely plane, there being only occasional low swells and ridges scarcely exceeding 20 feet in height.

Individual wells.—In the following list of wells are included sections of several published by Messrs. Gorby and Lee in the fifteenth report of the State geologist. But few well records were personally obtained.

In sections given by Gorby and Lee it appears that in the northwestern part of the county there is in many places a bed of sand between the yellow and blue till. In some cases the sand is but 3 or 4 feet in thickness, but it occasionally reaches a thickness of over 50 feet. There is usually below this sand a thick bed of blue till 50 to 150 feet. The following wells serve to illustrate the above statements.

Witt and Klizer's well at Thorntown penetrates—

	Feet.
1. Yellow clay	21
2. Quicksand	4
3. Blue clay	125
4. Shale, limestone, etc	193
Total	343

Mr. Duke's well, 3 miles north of Thorntown, penetrates—

	Feet.
1. Yellow till	18
2. Quicksand	12
3. Blue clay	153
4. Red sandstone	3
Total	186

A neighboring well at Mr. Wetherald's has a similar section. A well near Union Church, 3 miles east of Thorntown, penetrates—

	Feet.
1. Yellow till	27
2. Quicksand	9
3. Blue till	75
Total	111

Mr. Frank Harris's well, 1 mile south of Thorntown, penetrates—

	Feet.
1. Yellow till	19
2. Quicksand	4
3. Blue till	103
4. Cemented gravel	16
Total	142

William Mills's well, 1 mile west of Thorntown, penetrates—

	Feet.
1. Yellow till	25
2. Quicksand	3
3. Blue till	80
Total	108

At Charles Moffit's, 1½ miles west of Thorntown, a dry gravel was penetrated for 44 feet from the surface and the boring abandoned without obtaining water. Robert Woody's well, 3½ miles west of Thorntown, penetrates—

	Feet.
1. Yellow till	18
2. Fine white sand	55
3. Blue till	71
4. Limestone	3
Total	147

In the vicinity of Sugar Creek, near the west boundary of the county, the drift is only 20 to 40 feet in thickness, and is underlain by cherty limestone.

Wells are usually obtained in the village of Thorntown at 20 to 28 feet, and some wells at a depth of only 14 feet. In the valley bottom wells are mainly through sand and gravel, but on the bluffs they have sections similar to those noted above.

In the vicinity of Northfield, in the northeastern part of the county, wells are usually obtained in sand or gravel below a yellow till, at depths of 20 to 40 feet. In the vicinity of Slabtown, in the eastern part of the county, the water is obtained at depths varying from 20 feet to 50 feet. In this locality some blue till is usually penetrated above the water-bearing gravel.

A well about midway between Slabtown and Elizaville is reported to have penetrated a swamp muck below till at a depth of about 60 feet. The following section is reported by the well borer, Mr. Ball, of Thorntown:

	Feet.
1. Yellow till	18
2. Quicksand	3
3. Blue till	20
4. White sand, with inflammable gas	11
5. Blue clay	6
6. Swamp muck, leaves, twigs, etc	7
7. Blue clay	19
Total	84

A similar swamp muck was penetrated by Mr. Ball in a well for Mr. Vandeveer, 6 miles south of Lebanon. The well penetrates—

	Feet.
1. Yellow till	20
2. Blue till	45
3. Swamp muck, leaves, twigs, etc	10
4. Blue clay	25
5. Sandstone	9
Total	109

A similar muck was found at 48 to 60 feet in a well 4 miles north of Jamestown, and at 60 to 63 feet in a well 2½ miles north of Jamestown.

At the village of Roston, east of Lebanon, wells are usually obtained at from 8 to 20 feet in sand and gravel below a red clay.

In the vicinity of Ratsburg, northeast of Lebanon, water is usually obtained in sand below a gray till at about 20 feet.

At Lebanon the wells are but 12 to 24 feet in depth, with an average of about 16 feet. They are obtained in gravel, which has scarcely a sufficient amount of clay cover to insure freedom from surface contamination. The waterworks wells, however, are deeper.

A gas-well boring in the city of Lebanon penetrates 342 feet of drift. The specimens of the different kinds of material were examined by the writer, and the following section was determined:

	Feet.
1. Black soil	2
2. Yellow till	9
3. Blue till	15
4. Sand, with water	1½
5. Ash-colored till	77
6. Gravel	8
7. Pale ash-colored till	50 to 55
8. A darker ash or gray till, with some sand interbedded	176
Total	342

Below the drift is shale, 108 feet in depth, beneath which limestone of great thickness is penetrated.

Messrs. Gorby and Lee report the section of a well on Washington street, in Lebanon, 108 feet in depth, in which the structure is remarkably variable, as follows:

	Feet.
1. Soil (probably clay)	7
2. Yellow sand	1
3. Yellow clay	3
4. Blue sandy clay	1
5. Sand	4
6. Blue clay	3
7. Sand and gravel	4
8. Blue and gray clays	26
9. Sand and clay	10
10. Blue clay	23
11. Coarse gravel	1
12. Blue clay	25
Total	108

A well on D. M. Burns's farm, 2 miles north of Lebanon, is reported to penetrate—

	Feet.
1. Soil and yellow till	9
2. Gravel and sand	2
3. Blue till	22
4. Gravel	2
5. Gravel and clay	3
6. Blue till	74
Total	112

A well 4½ miles northeast of Lebanon enters rock at a depth of 285 feet. The section of drift was not ascertained.

A well on the farm of Clairborne Cain, 5 miles west of Lebanon, failed to reach rock at a depth of 243 feet. It penetrates—

	Feet.
1. Soil and yellow till	17
2. Quicksand	5
3. Blue till	51
4. Dry gravel with inflammable gas	5
5. Blue till	165
Total	243

Obstructions in the pipes made it necessary to abandon the boring without reaching the bottom of the blue till.

At the village of Jamestown wells are usually obtained at 25 to 30 feet. Gorby and Lee report the following sections at two deeper wells at this village. A well at the sawmill in Jamestown penetrates—

	Feet.
1. Soil and yellow till	11
2. Quicksand	1
3. Blue till	28
4. Gravel	2
5. Blue till	48
Total	90

A well at the gristmill in Jamestown penetrates—

	Feet.
1. Yellow till	11
2. Sand	2
3. Blue till	49
Total	62

Wells at New Brunswick are reported to obtain water at 11 feet to 35 feet. They usually penetrate considerable gravel in the upper 10 to 15 feet, below which there is a blue clay extending to the waterbed.

At Milledgeville the wells range in depth from 12 feet to 42 feet, and obtain water in sand and gravel between beds of till.

At Royalton water is usually obtained at depths varying from 10 feet to 40 feet. Foster and Leap had a well bored to the depth of 96 feet, penetrating—

	Feet.
1. Soil and yellow till	20
2. Gravel	5
3. Blue till, with frequent thin beds of sand and gravel	71
Total	96

A well at a sawmill in the same village, 107 feet in depth, had a similar section.

At Zionsville the wells are 20 to 60 feet, and are usually obtained from thin beds of gravel between till sheets. A gas-well boring in Eagle Creek Valley, near Zionsville, penetrates 165 feet of drift, of which the upper 40 feet is mainly sand and gravel and the remainder mainly blue till.

MONTGOMERY COUNTY.

General statement.—Montgomery County is situated in the west-central portion of the State, with Crawfordsville as its county seat. It has an area of 504 square miles. The altitude is somewhat uniform, the greater part of the county standing between 800 and 900 feet above tide. The surface is generally plane, or but gently undulating. In the northwestern part, however, there are morainic belts of considerable prominence. Moraines of gentle expression also occur east and southeast of the strong belts and traverse the eastern part of the county. The thickness of the drift is much less than in Boone County, rock being exposed on many of the streams at levels 50 feet or less below the bordering upland. There are, however, very deep valleys traversing the county, whose courses do not coincide with those of the present system and which are so completely obscured by the drift deposits which fill them as to be known only where deep borings have been made in them. One of these valleys is brought to light by borings in the vicinity of Crawfordsville. The drift of this county is apparently, in the main, a compact till, in which only thin beds of sand or gravel occur. Exposures along Sugar Creek, in the vicinity of Crawfordsville, show sheets of different constitution and age, testifying to more than one invasion of the ice. The county is well supplied with springs along its valleys, some being from limestone ledges and some from gravel in the Glacial drift.

Individual wells.—Over much of the northern part of the county wells are obtained at depths of 12 to 20 feet in beds of sand or gravel below the yellow till. They seldom reach a depth of 50 feet. A well at Pleasant Hill, in the northwest corner of the county, 47 feet in depth, penetrates a soft till for 37 feet, beneath which a much harder till is encountered.

Along a morainic belt in the western part of the county, near Alamo, wells occasionally reach a depth of 70 feet, mainly through till.

In the vicinity of Crawfordsville several gas wells have been drilled. One at Crawfordsville Junction penetrates 140 feet of drift, as follows:

	Feet.
1. Yellow till	12
2. Soft blue till	60
3. Hard blue till with gravelly beds	64
4. Gravel	4
Total	140

An attempted boring in section 33, near Crawfordsville, penetrated till 50 feet and then entered a bed of quicksand, which continued at least to a depth of 240 feet, where the well was abandoned. A boring in Sugar Creek Valley, near Crawfordsville, has about 200 feet of drift, mainly sand and gravel. Near the bottom there was a gray silt or

mud. In this connection it should be noted that rock outcrops occur within a mile north of Crawfordsville at a higher elevation than the mouth of the gas boring just mentioned.

The waterworks at Crawfordsville obtain the main supply from Van Cleve's springs. The water is collected in an impounding reservoir, from which it is pumped to the standpipe. Wells are also drawn upon, but the depth has not been ascertained. The private wells of the city vary greatly in depth and are obtained from beds of sand or gravel between sheets of till.

In the southern half of the county wells ordinarily obtain water at 25 to 30 feet in gravel or sand beds associated with the till. Blue till is entered at about 15 feet. Wells 50 feet in depth are rare. Near Wayland rock is sometimes struck at 20 or 30 feet, but a well in the village does not reach rock at 50 feet.

FOUNTAIN COUNTY.

General statement.—Fountain County is situated near the middle of the western part of the State, immediately south and east of the great bend of the Wabash River, that stream forming its north and west boundaries. The area is 390 square miles. Covington, the county seat, is situated at the west line of the county.

The greater portion is a very smooth plain underlain by till. There are, however, small morainic ridges traceable across the county. One leads in a southeastward course from Attica across its northeastern corner. This belt has a width of 2 or 3 miles and consists of a series of knolls and low ridges seldom more than 25 feet in height and rather loosely aggregated. A narrower morainic line is found along Coal Creek, in the southwest part of the county. This belt apparently separates into two, one of which follows the west border of Coal Creek northward to the Wabash, while the other passes eastward, through Rynear and Hillsboro, into Montgomery County.

Throughout much of the county rock is encountered at depths of 40 or 50 feet or less. Many wells in the northern portion find their water at the base of the drift at about 20 feet. Nearly all the streams of the county have outcrops of rock along them at levels only 30 to 50 feet above the bordering uplands. It is thought that the average thickness of the drift can not much exceed 50 feet.

There are numerous strong springs along the Wabash, issuing either from sandstone or from drift gravel.

Individual wells.—At Attica a strong artesian well has been obtained in the valley of the Wabash River, which supplies an excellent quality of water amply sufficient for the city. A large part of the population are in the habit of obtaining water from this well. A satisfactory record of the boring could not be obtained at the time of my visit, but it enters rock strata.

On the uplands south of Attica wells are usually obtained at 27 to

35 feet and are mainly through till. In some localities, however, as in secs. 1 and 2, T. 20, R. 8 W., wells enter sand below till at a depth of but 10 to 15 feet and continue in sand to a depth of 25 to 40 feet, where water is obtained. In section 11 of this township wells strike shale at 18 to 20 feet. In section 8 they enter blue till at 6 or 8 feet and reach a water-bearing sand at 15 feet to 25 feet. One well on the Wabash bluffs, near Attica, in sec. 34, T. 22, R. 7 W., reaches a depth of 60 feet without encountering rock.

Wells on the uplands east of Stone Bluff enter rock at about 20 feet. In the valley of Coal Creek, at Stone Bluff and Chambersburg, water is obtained in gravel and sand at a depth of 30 or 35 feet.

At Veedersburg the wells vary in depth from 20 feet up to 70 feet. They are mainly through blue till and seldom strike rock.

At Covington wells are obtained in gravel at 50 or 60 feet. The waterworks supply is from springs. An artesian well boring near the court-house, at an altitude 65 feet above low water in the Wabash, has a depth of 358 feet, terminating in the conglomerate sandstone. It penetrates 85 feet of drift, of which the upper 74 feet is gravel and the lower 11 feet blue till. The well does not overflow. The water is called "sulphur water." But little use is made of it at present.

Several wells in Mill Creek Township, in the southern part of the county, are reported to enter a black muck below till at about 25 feet. Beneath this muck is another till sheet harder than the one above it.

Borings for coal in the northeastern part of Fountain County are reported by Dr. Brown[1] to reach a depth of 100 to 130 feet in several cases before entering rock, though in the vicinity rock is usually found at 20 to 40 feet from the surface.

A salt-well boring in sec. 4, T. 18, R. 8 W., was sunk to a depth of 1,004 feet and passed several veins of salty water, the first being at a depth of only 72 feet. The drift at this point is 40 feet in depth.

A boring near Lodi, on the southern border of the county, was sunk to a depth of 1,155 feet, and obtains a strong flow of salt water. There is also a strong flow of sulphur water, struck at a depth of 1,051 feet. The analysis of the water from this well is given elsewhere.[2]

VERMILION COUNTY.

General statement.—Vermilion County is situated near the middle of the west border of the State, and occupies a narrow strip between the Wabash River and the State line, the length of the county being 36 miles and the width 6 to 10 miles. Its area is 270 square miles. The greater part of the county is a till plain, standing about 200 feet above the Wabash River. It is crossed, however, from west to east by two small moraines, one following the south border of the Big Vermilion Valley, the other the south border of the Little Vermil-

[1] Eleventh Ann. Rept. Indiana Geol. Survey, p. 92.
[2] Eighteenth Ann. Rept. U. S. Geol. Survey, Part IV, p. 498.

ion. The former comes to the Wabash Valley at Eugene, the latter at Newport, the county seat. In the northern portion of the county the gravel terraces of the Wabash, standing 75 to 100 feet above the river, extend back a mile or more from the stream. There are also extensive remnants of the gravel terrace near Clinton, in the southern part of the county.

Individual wells.—On the till plain, in the northern part of the county, wells enter a blue till at about 6 or 8 feet, and obtain water in the beds of gravel or sand associated with the till at depths of 15 to 25 feet. There are very few deep wells, though the record of one 56 feet in depth was obtained. This is situated near the State line, in the northwest corner of the county, and is mainly through blue till.

Wells on the gravel terrace of the Wabash, in the northern part of the county, are often sunk to depths of 60 or 80 feet, and occasionally 100 feet, through sand and gravel, before entering a water bed. In passing westward from the river the gravel becomes shallower, and till is encountered before reaching the level of the river. It is not rare to find beds of muck containing wood and leaves at the base of the gravel. This muck is thought to be an interglacial flood-plain covered by glacial gravels of a later invasion.

In the villages of Eugene and Cayuga, which are situated on a low terrace of the Wabash near the mouth of Big Vermilion River, wells are ordinarily obtained at 40 feet or less, at about the level of the Wabash River.

On the uplands west of Eugene, in section 8, and at an altitude about 160 feet above the Wabash River, a boring 241 feet in depth failed to reach rock or obtain water. It was mainly in a compact blue till.

At Newport the wells range in depth from 12 feet to 88 feet, and obtain water in gravel between sheets of till.

At Clinton wells are usually sunk to a depth of 60 to 75 feet in gravel, and obtain water at about the level of the Wabash River. A boring for coal at this village, made on the low bottom of the Wabash, penetrated 100 feet of drift before entering rock.

On the uplands, in the southern part of the county, wells are ordinarily obtained at about 30 feet, in gravel between till sheets.

PARKE COUNTY.

General statement.—Parke County is situated in western Indiana, immediately opposite the southern portion of Vermilion County, on the east side of the Wabash River. It has an area of 440 square miles. Rockville is the county seat.

Several large creeks traverse the county in a northeast to southwest direction in valleys cut to a level 100 to 150 feet below the bordering uplands, and these streams, with their numerous tributaries, cause a somewhat broken surface. Between the streams, however,

there are strips of level upland, preserving the original elevation of the plain. A series of drift ridges traverse the central portion of the county in a northeast to southwest direction. These ridges are but 30 to 50 feet higher than bordering plains and have a gently undulating surface. They are, therefore, not conspicuous features.

The southern portion of this county extends beyond the limits of the Wisconsin drift sheet and its surface is covered with a nearly pebbleless white clay, several feet in thickness, which rests upon a sheet of older drift of Illinoian age. The central and northern portions of the county and a narrow belt along the Wabash, in the southern portion, are covered by the later sheet of till. Wells are often obtained at the junction of the two drift sheets at depths of 20 to 40 feet on plane tracts and somewhat greater depth on the moraines or drift ridges. The later drift is readily distinguished from the earlier by its softness and its fresher appearance. Wells may be readily spaded or bored in the newer drift, while in the older a drill or pick must be substituted. The hardness of the older till sheet is largely due to a partial cementation with carbonate of lime.

The thickness of the drift varies greatly, not because of variation in the surface elevation, but because of the greatly eroded rock surface upon which the drift lies. There are numerous outcrops along streams at levels only 50 to 75 feet below the general level of the upland, but it is probable that the average thickness of the drift of the county exceeds 100 feet.

Springs are not so numerous or strong as in the adjoining counties, Fountain and Montgomery, and are not an important water resource.

Individual wells.—Wells are usually obtained in beds of sand and gravel, between sheets of drift or near the base of the drift, at depths varying from 10 or 15 feet up to 100 feet or more. The knowledge of the thickness of drift is obtained from coal shafts or test borings for coal rather than wells, there being numerous shafts and borings in the southern part of the county.

In the northeastern part of the county, on the plain north of Sugar Creek, wells are usually obtained at about 30 feet. They enter blue till at 12 or 15 feet.

On the plain south of Sugar Creek records of several wells show a depth of 30 to 36 feet, but in the village of Annapolis the wells seldom reach 30 feet.

In the northwest part of the county, on the bluffs of the Wabash, wells are occasionally 50 feet in depth. One of these wells, a mile north of the mouth of Sugar Creek, at an altitude 150 feet above the Wabash River, has the following section:

	Feet.
1. Sand	8
2. Gravel	10
3. Sand	25
4. Blue till	5
Total	48

The amount of sand at this point is exceptional, though there is generally a narrow belt of sand along the immediate brow of the bluff.

At the village of Howard, on a terrace 80 feet above the Wabash, wells obtain water near the bottom of the gravel at about 40 or 50 feet. At Lodi, on a lower terrace, 35 feet above river level, wells are obtained at 35 or 40 feet. Near West Union, also on a high terrace, wells obtain water at 75 feet, or about the river level.

At Montezuma an artesian well 1,707 feet in depth, situated on a terrace of the Wabash about 50 feet above the river, penetrates 128 feet of drift. Salt water was struck at a depth of 298 feet and at lower levels, and sulphur water at 1,205 feet. The water has a head at least 100 feet above the mouth of the well. The ordinary wells at Montezuma are usually obtained at a depth of about 60 feet in the gravel, but have a range from 30 feet to 70 feet.

At Bloomingdale wells are obtained at a depth ranging from 12 feet to fully 60 feet. Ordinarily the water-bearing sand and gravel is found beneath the yellow till at 10 to 16 feet. The deeper wells penetrate blue till. Sandstone is occasionally struck at about 50 feet.

On a morainic ridge near Marshall wells are usually obtained at 30 feet or less.

In the vicinity of Bellmore wells sometimes enter rock at about 30 feet. Usually water is obtained without penetrating the rock.

At Rockville, the county seat, there is no definite horizon at which wells are obtained, those on adjoining lots varying greatly in depth and in the character of material penetrated. The depth ranges from 15 feet to about 75 feet. Ordinarily wells reach the bottom of the newer drift at about 25 feet, and encounter considerable wood at that horizon. A gas-well boring located in the higher part of town penetrates 96 feet of drift. A well on the moraine just west of Rockville has 158 feet of drift, of which the upper 35 or 40 feet is newer drift and the lower 125 feet is the older drift. A well 2 miles southwest of Rockville, 92 feet in depth, penetrates a soft till 17 feet, beneath which is a hard till whose bottom is not reached.

The city of Rockville contemplates waterworks from deep wells bored in a valley east of the city. Two borings 260 feet in depth have been sunk for the purpose of obtaining a supply, but the supply scarcely seems adequate.

Wells along the morainic ridge on the east bluff of the Wabash River in the south part of the county have in several instances passed through a black soil below the newer till sheet at about the level of the base of the morainic ridge. The distance to the soil varies in the different wells with the variations in elevation of the ridge, and there is a known range from 17 to 75 feet. Often water is obtained at slight depth beneath this buried soil from the upper portion of the older drift sheet.

On the uplands west of Rosedale coal shafts penetrate 50 to 75 feet

of drift, mainly till and entirely in the older drift sheet. Wells are obtained in the village of Rosedale at depths of 12 to 25 feet.

In the southeastern part of the county coal shafts often encounter much sand and gravel in the lower portion of the drift at depths of 30 to 60 feet from the surface. Wells range in depth from 20 to 100 feet, but are usually obtained at less than 30 feet. Mr. Minchell's well, in section 30, Jackson Township, 62 feet in depth, penetrates—

	Feet.
1. Surface clay and till	15
2. Hard blue till	45
3. Sand with water	2
Total	62

A boring in section 24 of an adjoining township on the west, 96 feet in depth, penetrates—

	Feet.
1. Surface sand	17
2. Hard blue till	29
3. Sand and gravel	10
4. Hard blue till	16
5. Sand and gravel	4
6. Hard blue till	20
Total	96

PUTNAM COUNTY.

General statement.—Putnam County is situated in the west central part of the State, with Greencastle as its county seat. It has an area of 490 square miles. The southern portion of the county is moderately hilly, there being insufficient drift to fill the preglacial valleys. The northern portion, although nearly as elevated as the southern, has a comparatively smooth surface, a result of the greater amount of drift filling. The hilly southern portion of the county carries only the older drift sheet. The northern portion carries also the newer drift. The southern boundary of the newer drift passes from northwest to southeast across the central portion of the county, entering on the west about 10 miles from its north boundary and leaving the county on the east about 5 miles from its south boundary. The city of Greencastle is situated very near the border of this later sheet of drift. Both drift sheets are composed largely of till, but, as in Parke County, the older drift is much harder to penetrate than the newer. The thickness of drift in the portion where both sheets are present probably averages not less than 100 feet, though there are numerous places where the rock is entered at 10 or 20 feet or less. In the southern portion of the county, where only the older drift is present, the thickness on hills and ridges seldom reaches 20 feet, but in the valleys or lowlands it is much thicker and probably in some cases exceeds 100 feet. The wells in this portion of the county usually obtain water in the rock when on the hills and ridges, but when on lowlands they obtain water in the drift.

There are a few springs along the valleys, but they seldom constitute an important water resource.

Individual wells.—At Fincastle, in the northern part of the county, wells on the low ground find no rock at 30 feet, but south from this village on the higher ground rock is struck at 20 or 30 feet. In sec. 8, T. 15, R. 4 W., a well in a valley obtains a flow at 20 feet without entering rock.

In the vicinity of Bainbridge, on an elevated ridge, several wells reach a depth of 80 feet before entering rock. Two such wells are found in the village, one at a sawmill and the other just north of the railway depot. About a mile northeast of Bainbridge, on ground probably 40 feet lower, wells enter rock at a depth of 20 feet.

Records of several wells were obtained in the southwestern part of the county on nearly plane tracts outside the limits of the later drift sheet, which enter rock at about 20 feet.

On the hills in the southern part of the county wells drilled into the rock range in depth from 20 feet or less up to fully 100 feet. There is apparently no definite horizon at which water may be obtained. In the northern portion of the county wells are seldom drilled far into the rock before obtaining water.

HENDRICKS COUNTY.

General statement.—Hendricks County is situated in the central portion of the State, immediately east of Putnam County. Its county seat, Danville, is near the geographic center. It has an area of 400 square miles. This county was entirely covered by the ice at its later as well as its earlier invasion, and has in consequence a smooth surface, with the preglacial ridges and valleys almost concealed. A moraine of moderate proportions traverses the northwestern part of the county in a northwest to southeast direction, passing just west of the city of Danville. It fades away a few miles south of Danville into a gently undulating plain, where its continuation is traceable chiefly by the belt of bowlders which is an accompaniment of the morainic belt. The breadth of this moraine is 2 to 5 miles, being widest in the vicinity of Danville. Aside from this belt, the county has a gently undulating surface.

The drift is principally a compact till, though there are small areas in which it assumes a gravelly constitution. In its deeper portions also it often contains considerable sand and gravel. There are few places in which the writer was able to distinguish the older from the newer drift in this county, and it is thought that the greater portion of the drift belongs with the later ice invasion. In the southern portion of the county rock is often struck in wells at depths of 20 to 50 feet, but in the northern portion the rock appears to be buried to a depth of 100 to 150 feet.

Individual wells.—At North Salem, in the northwestern part of the county, records of two deep wells were obtained, one 70 feet, the other

85 feet, neither of which entered rock and both were mainly through blue till. Wells in that village are often obtained at about 20 feet.

At Lizton, and also at Brownsburg, in the northern part of the county, the wells are obtained at shallow depths, seldom so much as 40 feet. In the farming districts, also, wells are obtained usually at shallow depths. The great thickness of drift in the northern part of the county has been made known by gas borings, of which there are several.

At Plainfield, in the eastern part of the county, wells are usually obtained at 35 or 40 feet, though some are of less depth. Rock is struck in the gas boring at about 90 feet.

At Danville the waterworks obtains its supply from flowing wells 110 feet in depth, which do not reach the rock. A 3-inch well is estimated to furnish about 2,000 barrels per day. There are two 3-inch wells and two 2-inch wells in use. Private wells are obtained in Danville at about 40 feet. A well at the court-house penetrates—

	Feet.
1. Yellow till	15
2. Blue till	25
3. Sand and gravel	5
Total	45

The gas borings at Danville penetrate about 160 feet of drift.

At Clayton wells are obtained at 10 to 25 feet. They are mainly through till, but some have considerable sand and gravel.

At Amo wells 40 to 50 feet in depth do not reach rock. They usually penetrate about 25 feet of yellow till. On the plain north of Amo a blue till is struck at 10 or 15 feet.

At Coatsville wells are mainly through till to a depth of 25 or 30 feet without striking rock. A well 1 mile south of this village, however, enters rock at 8 feet.

At Reno two wells enter rock at about 25 feet, but several obtain water in the drift.

A well on an elevated point about 5 miles north of Reno strikes rock at 70 feet, but a neighboring well on lower ground does not strike rock at 90 feet. There are outcrops of rock along the creek in Sec. 29, T. 16, R. 2 W., in the neighborhood of these wells.

MARION COUNTY.

General statement.—Marion County is situated just south of the center of the State, with Indianapolis, the State capital, and also the county seat, near its geographic center. It has an area of 400 square miles. White River traverses the county nearly centrally from north to south. Throughout much of its course in the county it is bordered by a broad gravel plain, averaging, perhaps, 2 miles in width, though much narrower at the northern border. This gravel plain is underlain by till, and the entire county is covered thickly with a sheet

of compact till. In a few places rock is struck at 30 to 50 feet, but throughout much of the county the drift exceeds 100 feet, and in places is about 250 feet in thickness. In the southern and southeastern part the surface is more undulatory than in the northern and western part, swells 20 or 30 feet in height being numerous, while occasional ridges reach a height of 50 or 75 feet. This undulatory drift is continued on the east in a more sharply defined morainic belt, of which mention is made in the reports on Hancock, Henry, and Randolph counties. West from White River this belt is very poorly defined, and some uncertainty is felt concerning its line of continuation.

The dug wells in this county are often obtained at a depth of 10 to 20 feet, near the junction of the yellow and blue tills, where sand beds often occur. Tubular wells are usually sunk to much greater depth, and in nearly every township several may be found which exceed 100 feet. The great majority penetrate a large amount of blue till. The water appears to be obtained in comparatively thin beds of gravel and sand associated with the till.

Individual wells.—At the city of Indianapolis, which is situated on the gravel plain bordering White River, a large amount of water may be obtained near the base of the gravel at depths of 30 to 50 feet. As there is no overlying stratum of clay contamination is liable to occur. This fact being appreciated, many tubular wells, known as Rouse wells, have been sunk to depths ranging from 60 to 90 feet, and water is obtained in gravel beneath a sheet of blue till. The city waterworks obtains about three-fourths of the supply from wells. These wells obtain water both from the surface gravel and the deeper beds. The remainder of the water supply is obtained from White River, and is filtered before it is pumped to the mains. The waterworks company have sunk a number of deep wells with a view to obtaining a larger and better supply. Rock is entered at about 80 or 85 feet. The deepest well reported has a depth of 343 feet. From these deep wells water rises a few feet above the level of the water in White River. It is hard and contains some sulphur and also considerable iron. The mineral ingredients, however, are not considered objectionable.

The thickness of drift at several points in the county and the sections of a few borings have been obtained from gas companies. The Capital City Gas Company have several wells in the northeast part of the county which penetrate 140 to 230 feet of drift, of which a large part is blue till. There are, however, beds of sand and gravel which would afford an abundant supply for water wells. In the eastern part of the county the thickness of the drift at several villages is as follows: Oakland, 231 feet; Lawrence, 188 feet; Brightwood, 190 feet; Irvington, 130 feet; Cumberland, 230 feet. At Cumberland the drift is reported to consist of till, mainly of blue color, 50 feet, followed by

alternations of till with sand or gravel, each a few feet in thickness, 180 feet.

At Indianapolis the drift usually exceeds 80 feet, and in one well near the Union Depot reaches a depth of 118 feet. This well, which is located between Pine and Delaware streets, has the following section of drift:

	Feet.
1. Sand and gravel	45
2. Gray till	15
3. Alternations of till with sand and gravel	58
Total	118

A well about a mile south of the Union Depot, on Meridian street, enters rock at 80 feet. The drift section is as follows:

	Feet.
1. Sand	10
2. Till	25
3. Gravel, a few feet.	
4. Till, several feet.	
5. Quicksand, extending to the rock.	

At the waterworks borings, referred to above, a section of one well was obtained, as follows:

	Feet.
1. Sand and gravel	45½
2. Blue till	20
3. Sand and gravel	15
4. Limestone struck at 82 feet 7 inches.	

There was continuous limestone from this depth to the bottom of the well at 343 feet.

North from Indianapolis, in the vicinity of Broad Ripple, records of 30 wells were obtained, all located in the White River Valley, which show the drift to range from 45 feet to 90 feet. It is mainly sand and gravel, though thin sheets of till occur. Two wells in the valley, near Allisonville, have 70 feet of drift, mainly blue till. At Castleton, on the uplands east of White River, the drift is 78 feet, mainly till.

A gas boring in the west part of the county, at Bridgeport, has 100 feet of drift, as follows:

	Feet.
1. Creek alluvium	8 or 10
2. Alternations of blue till with sand	30
3. Quicksand	10
4. Blue till	40
5. Gravel and sand	10
Total	100

A well near Bridgeport penetrates 280 feet of drift, but an accurate section was not obtained.

At Glen Valley, in the southern part of the county, on the border of the White River gravel plain, records of two wells were obtained which are through sand and gravel to a depth of 53 and 56 feet. Wells are usually obtained, however, at less depth.

HANCOCK COUNTY.

General statement.—Hancock County is situated in the east-central part of the State, immediately east of Marion County, with Greenfield as its county seat. It has an area of 307 square miles. Like Marion County, it is covered thickly with a sheet of till. The southern half has an undulatory surface, with numerous swells 20 or 30 feet in height. The northern part has a nearly plane surface. The entire county has a gradual descent from east to west, the altitude at the eastern border being about 1,000 feet, while at the western it is scarcely 800 feet above tide. In this county, as in Marion, dug wells may usually be obtained at 10 to 20 feet at the junction of the yellow and blue tills. Tubular wells are usually 50 to 100 feet or more in depth.

Individual wells.—In the vicinity of Greenfield wells usually obtain a good supply of water at about 30 feet below a bed of till. The waterworks wells are sunk to the rock, near the top of which they obtain water at a depth of 176 feet. In these wells the water rises a few feet above the surface, and an 8-inch well is estimated to furnish 150 gallons per minute.

At the village of Philadelphia wells are usually obtained at about 20 feet after penetrating yellow till and a few feet of blue till.

In the vicinity of New Palestine, in the western part of the county, wells are usually obtained at 25 or 30 feet. The gas-well boring at this village penetrates 285 feet of drift.

At McCordsville, in the western part of the county, wells are usually obtained at depths of 40 feet or less. The drift at this point is 186 feet, mainly till.

In the eastern part of the county wells in the villages are usually obtained at about 20 feet, but on farms tubular wells are often sunk to much greater depth. Several gas-well borings in this part of the county penetrate about 200 feet of drift, mainly blue till.

HENRY COUNTY.

General statement.—Henry County is situated in the eastern part of the State, with Newcastle as the county seat. It has an area of 400 square miles. A moraine traverses the county from southwest to northeast (passing west and north of the city of Newcastle), which constitutes the divide between the West White and East White rivers. In the northeastern part of the county it is a prominent feature, with sharp knolls and ridges, in some cases 50 to 75 feet or more in height, among which are winding sloughs and shallow basins. In the western and southwestern part of the county the expression of the moraine is more subdued. From this moraine there is a rapid descent to the northwest; but eastward from the moraine the surface continues elevated and has an altitude 1,000 to 1,100 feet above tide. On the eastern border of the county there is a moraine with gently undulating

surface which constitutes the divide between the East White and the Whitewater River system. There is also a small moraine leading south from the central part of the county, along the border of Flat Rock Creek. Between these moraines there are plane tracts with slightly lower elevation than the morainic ridges. The northwest corner of the county is also a plain.

This county has, perhaps, the thickest drift to be found in the State, one well near Newcastle having penetrated 500 feet before striking rock and one at Cadiz more than 400 feet. The drift of this county, as in the counties to the west, is largely composed of a compact blue till.

Individual wells.—The general depth of wells in this county is no greater than in the counties with lower elevation on the north and west, there being usually an adequate supply of water at 20 to 40 feet. In a few places, water not being abundant, tubular wells have been sunk to depths of 100 feet and occasionally 200 feet, or even more.

At Newcastle the private wells range in depth from 12 to 50 feet, the majority being about 20 feet. The waterworks wells sunk in the valley of East White River range in depth from 90 to 250 feet and are obtained in all cases in gravel, associated with sheets of till. One of the shallower waterworks wells is reported to have the following section:

	Feet.
1. Clay	10
2. Gravel	15
3. Quicksand	25
4. Blue clay	31
5. Gravel	2
6. Hard till	7
7. Coarse gravel, with water at bottom.	
Total	90

The waterworks wells have a head about 20 feet above the surface. Analyses of the water from two of these wells are given elsewhere.[1] Gas-well borings in the vicinity of Newcastle show 300 to 500 feet of drift on the borders of the East White River Valley, but on the upland plain east of Newcastle, at an elevation of 75 feet or more above the valley, rock is struck at about 250 feet.

At Moreland, in the northeast part of the county, in the valley of Flat Rock Creek, the drift is 150 feet, largely till, but a bed of gravel at about 90 feet furnishes a flow of water.

At Mount Summit, in the northern part of the county, on an elevated part of the moraine, the drift is shown by a gas-well boring to be 235 feet, mainly sand and gravel. At Springport, on the north slope of the same moraine, the drift is 170 feet and is largely till. Two miles north of Springport rock is struck at 156 feet.

At Luray a boring for water 240 feet did not reach rock.

[1] Eighteenth Ann. Rept. U. S. Geol. Survey, Part IV, p. 499.

At Honeycreek station, on the plain in the northwest part of the county, the drift exceeds 200 feet, and at Sulphur Springs is about 250 feet. At Middletown, in the extreme northwest corner of the county, a boring on the upland plain, north of Fall Creek, enters rock at 203 feet. The drift is mainly sand and gravel. About 2 miles south of Middletown a gas boring penetrated more than 200 feet of drift and passed through a log near the bottom. A well in Fall Creek Valley, at Middletown, strikes rock at 160 feet. A flow of water was obtained at 82 feet. In this well also logs were penetrated at a depth of about 75 feet.

At Cadiz, on the moraine in the west-central part of the county, a gas boring penetrates 421 feet of drift. About midway between Cadiz and Newcastle, on a plain east of the moraine, the drift is 303 feet. At Greensboro, about 5 miles below Newcastle, in the East White River Valley, rock is struck at less than 200 feet, and outcrops of rock occur farther down the river in the vicinity of Knightstown. At Kennard, in the west part of the county, a gas well penetrates 247 feet of drift, consisting of alternations of till with gravel and sand.

In the village of Knightstown private wells are usually obtained at a depth of 20 to 40 feet in gravel beds below clay. The waterworks wells are obtained near the top of the limestone, at a depth of 57 and 58 feet.

At Ogden, 5 miles east of Knightstown, the drift is 154 feet, of which the upper 20 or 30 feet is sand and gravel and the remainder till.

In the vicinity of Spiceland, on a plain east of White River, the drift ranges in depth from 90 feet up to 150 feet, and is largely till.

In the vicinity of Dunreith, on the south border of the county, the drift ranges from 160 to 215 feet, the greatest depth being found in a well 1 mile northwest of the village.

At Lewisville, on the border of Flat Rock Valley, 247 feet of drift is penetrated, mainly sand and gavel.

WAYNE COUNTY.

General statement.—Wayne County is situated on the east border of the State, with Richmond as its county seat, and has an area of 380 square miles. Like the bordering counties on the north and west, its altitude is high. Its general elevation falls but little below that of Randolph County, the highest county in the State. At the north boundary, near the Randolph County line, the elevation is 1,150 to 1,200 feet or more. The northern one-third of the county probably has an average altitude of not less than 1,100 feet. There is a gradual southward descent across the county, and its south border is slightly below the 1,000-foot contour, except perhaps for a few miles near the State line.

Several drainage lines, having remarkably large valleys, traverse

the county in a general north to south direction, among which may be mentioned Nettle Creek, West Fork, Martindale Fork, Greens Fork, and Nolands Fork, all of which unite to form the West Whitewater. A profile across the county from west to east, in its northern part, oscillates 100 to 150 feet in crossing these valleys and the ridges which separate them. The valleys or troughs are larger than the present stream channels, for the immediate bluffs rise but a few feet above the stream beds. These troughlike valleys are cut in a sheet of old drift, over which a thin sheet of later drift has been spread, a sheet whose southern boundary is found in counties immediately south. Along the eastern part of the county the rock has a higher general elevation than in the central and western portion, and here the principal drainage line, East Whitewater, has a postglacial channel partly excavated in the rock. With the exception of the southeastern part of the county the drift deposits are generally 150 to 200 feet or more in thickness.

There are extensive gravel plains in the western part of the county, bordering the valleys of Nettle Creek, West Fork, and Martindale Creek. For a few miles above the mouth of Martindale Creek, at Cambridge City, the gravel plain occupies the entire interval between West Fork and this stream, but in the northern portion of the county the valleys are separated by a ridge of till. Narrow, gravelly belts occur also along Greens Fork and Nolands Fork, but they seldom reach a width of a mile. These gravel deposits are apparently the outwash from the ice-sheet at the time it formed the strong moraine at the headwaters of these streams in southern Randolph County. On these gravel plains wells are usually obtained at about the level of the streams, 20 to 40 feet. On the uplands between these gravel plains the drift usually consists of till, and wells are obtained at moderate depths, seldom more than 40 feet.

Individual wells.—At Hagerstown, in the northwest part of the county, flowing wells are obtained in the valley of Nettle Creek at a depth of about 80 feet. They are largely through gravel, but penetrate a bed of till just above the water vein. In eight gas borings made in the vicinity of Hagerstown, along the valley of Nettle Creek, the drift has an average depth of about 100 feet. The least distance to rock is 78 feet.

At Williamsburg, in Greens Fork Valley, in the north part of the county, wells are obtained at 18 to 25 feet, mainly in gravel. At Fountain City, in the valley of Nolands Fork, wells are obtained at similar depth. A gas boring at Fountain City penetrates 185 feet of drift.

At Richmond wells are obtained at from 12 to 40 feet. In a few instances water is obtained in the drift, but usually the wells enter the limestone. The city water supply is obtained from springs. Professor Dennis, chemist of Earlham College, reports that the waterworks supply and also water from the river is of excellent sanitary

quality, but he has found by analysis that the wells contain 10 to 30 times as much chlorine as is found in the river water above the city, and he states that more or less malaria constantly exists where wells are used.

At Centerville, near the valley of Nolands Creek, a gas-well boring penetrates 176 feet of drift, mainly blue till. Ordinary wells are obtained at 30 or 40 feet, more or less. Another gas boring is reported by Dr. Phinney to have about 250 feet of drift, with a flow of water at 246 feet.

At Cambridge City, in the valley of West Whitewater River, wells are usually obtained in gravel at 15 to 25 feet. Two gas-well borings at this city enter rock at about 100 feet. After passing through 15 or 20 feet of gravel the drift is mainly blue till.

On the uplands east of the West Whitewater, in the southern part of the county, water wells in some cases reach a depth of 80 feet without striking rock. On the uplands west of this stream, gas-well borings have shown the drift to have a thickness of 150 to 300 feet, the greatest thickness noted being found in the village of Dublin. There are, however, outcrops of rock along the Whitewater, in the vicinity of Cambridge City, showing that the rock surface has a variation of fully 200 feet within 1 or 2 miles of that city.

On a plain south of Richmond, in the southeast corner of the county, wells have, in some instances, been sunk to a depth of 60 feet through till without entering rock. As a rule, however, rock is found in that part of the county at 50 feet or less, and over quite extensive areas it has outcrops nearly as high as the bordering upland.

Dr. Phinney reports the drift in a gas boring at Dalton, in the northeast corner of the county, to be 275 feet and at Walnut Level, in the western part, 280 feet. At Washington, near the center of the county, it is 212 feet.

UNION COUNTY.

General statement.—Union County is situated on the east border of the State, between Wayne and Franklin counties, with Liberty as its county seat, and has an area of 170 square miles. Its western part is traversed from north to south by the East Whitewater, which occupies a rather broad valley 100 feet or more below the adjacent upland on the east and west. The eastern part of the county is nearly plane. The drift filling is sufficient to give a smooth surface to what would otherwise be a hilly district. Although rock is often struck at depths of 20 to 40 feet where ridges or preglacial uplands occur, it is apparently buried to a depth of 200 feet or more in the larger valleys. The greater part of the drift is a compact till, but wells are usually obtained at convenient depths in beds of sand or gravel associated with it. They rarely exceed a depth of 50 feet and are usually less than 25 feet.

Individual wells.—A few tubular wells in the eastern part of the county reach depths of 50 to 90 feet and penetrate—

	Feet.
1. Yellow till	10 to 12
2. Blue till	40 to 80

At Bechy Mire, in the northeast part of the county, a well at Mr. Lybrook's is reported to have entered a hard yellow till below a soft blue till at a depth of 33 feet. A well 3 miles southeast of Liberty enters a hard yellow till below soft blue till at a depth of 35 feet. A well at the Pyle House, in Liberty, passes through a bed of swamp muck, with leaves below blue till at a depth of 35 feet. Beneath the muck, sand was penetrated, in which water was obtained at 52 feet. At Joseph Coffman's, 2 miles south of Brownsville, a well passes through a bed of swamp muck below gravelly drift at 20 or 30 feet. It seems probable that the swamp muck and the hard yellow till, found in the four wells just mentioned, pertains to a drift sheet much older than the overlying drift.

At Liberty water is usually obtained at 30 to 45 feet in sand and gravel below till. At the waterworks a supply is obtained at a depth of 21 feet in sand below clay. A partial analysis shows the presence of chlorine in sufficient amount to indicate that the water may be contaminated, and suggests the advisability of obtaining water from a better source. The drift at Liberty is 60 to 90 feet in depth and is underlain by a limestone which is likely to yield an abundance of water at convenient depths.

There is a flowing well about 3 miles southeast of Liberty, on Mr. Bratton's farm, 42 feet in depth, from sand below till.

In the extreme southeast part of the county rock is struck at 5 to 20 feet. Wells in the vicinity of Lotus, 35 or 40 feet deep, do not enter rock; they are mainly through till.

FAYETTE COUNTY.

General statement.—Fayette County is situated in the eastern part of the State, with Connersville as its county seat. It has an area of 210 square miles. It is traversed nearly centrally from north to south by the broad valley of the West Whitewater River, which carries a gravel plain 1 to 2 miles in width. At the later ice invasion there was a reentrant angle in the ice sheet in southeastern Indiana which had its northernmost point in the Whitewater Valley, in southern Fayette County. The boundary at this later invasion is marked by a well-defined though not bulky morainic ridge. The ridge formed on the western side of the reentrant angle enters Fayette County from southeastern Rush and northwestern Franklin counties and passes northward, coming to the Whitewater Valley about 4 miles below Connersville. Here it meets the ridge formed on the east side of the reentrant angle, and from that point northward an interlobate moraine

was formed which extends northward into Wayne and Henry counties. Through the midst of this interlobate moraine the Whitewater River has its passage. On either side of the Whitewater, in the south part of the county, there is a small district in which the newer drift is absent, and a coating of white clay or silt several feet in thickness covers the till of the earlier invasion. Here, as has been noted in other counties of Indiana, the older drift sheet is much more highly oxidized and harder than the newer sheet. In the newer drift wells may be easily spaded or bored, while in the older drift a pick or drill must often be used.

Rock is seldom encountered on the uplands of this county at less than 50 feet, and there appears to be generally 100 feet or more of drift. The drift consists mainly of a compact till, though wells are usually obtained in sand or gravel associated with the till at depths of 35 feet or less.

Individual wells.—At Connersville the water vein is found in gravel at a depth of about 30 feet near the level of the Whitewater River. Below this depth till is often found under which there is a water-bearing gravel at a depth of 60 to 80 feet from the surface. There appears to be danger of contamination in the shallower wells, but the deeper wells are thought to be free from such contamination. The city waterworks obtain the supply from the Whitewater River, but the domestic use is mainly from wells.

A few records of farm wells were obtained both on the east and west of the Whitewater Valley. The deepest one, near Alquina, is only 43 feet, the others range from 30 feet down to 20 feet. In nearly all the wells till constitutes the main part of the section. It is probable that those located on the newer drift are not sufficiently deep to reach the older sheet of till.

RUSH COUNTY.

General statement.—Rush County is situated in the eastern part of the State, with Rushville as its county seat, and it has an area of 414 square miles. It has a nearly plane surface, though a small moraine crosses its southeast corner and another one traverses its western half from north to south, following the west border of Flat Rock Creek. There is a general southwestward descent, the altitude in the northeast corner being nearly 1,100 feet, while the southwest corner falls below 900 feet. The drift is composed mainly of till, though the lower part is frequently sand and apparently has an average thickness of fully 100 feet. The county has been covered entirely by the later ice invasion as well as by the earlier one. The extreme limits of the later invasion are, however, just outside the southeastern border of the county, at the moraine above noted. Along Flat Rock Creek, in the northern part of the county, there is a gravel plain covering several square miles, which lies immediately outside and

southeast of the moraine referred to above, and is, in all probability, an outwash from it. There is also a gravel plain along East White River, in the northwest part of the county, probably formed from the moraine situated on its west border.

Individual wells.—In the vicinity of Raleigh, on the gravel plain in the north part of the county, several flowing wells have been obtained at depths ranging from 65 to 106 feet. They have a head 3 to 6 feet above the surface. The water is obtained from gravel below a sheet of till, but the wells penetrate a large amount of surface gravel before entering the till.

Along the moraine in the northern part of the county and on the plain west of it wells usually enter sand below till at 12 to 25 feet. In some cases the wells have been sunk some distance into sand before obtaining water. At Hamilton Station one well penetrates 92 feet of sand.

Near Carthage, in the northwestern part of the county, on the gravel plain along East White River, rock is sometimes struck at a depth of 50 feet, and the drift is mainly gravel. At Arlington, in the western part, wells are usually obtained in sand below till at a depth of 20 to 30 feet.

At Homer the drift is mainly sand after penetrating a few feet of surface till, and water is obtained at 20 feet or less. The gas well enters rock at 53 feet.

A gas well 7 miles north of Rushville penetrates 147 feet of drift—mainly sand, 92 feet; blue till, 55 feet.

At Rushville a gas well near the school building penetrated 60 feet of drift, mainly till. Water wells at Rushville are obtained at depths ranging from 14 to 75 feet. Several flowing wells have been obtained from the drift in and near the city along the valley of Flat Rock Creek. They are strongly chalybeate and also sulphurous.

At Glenwood, near the eastern border of the county, a gas well penetrates 120 feet of drift, of which the upper 60 or 70 feet is till and the remainder sand and gravel. Wells are obtained in the vicinity of that village at depths of 20 feet or less, though an occasional tubular well is sunk to the underlying heavy bed of sand.

At New Salem, in the southeastern part of the county, wells are obtained in sand below till at 40 or 50 feet.

Along the morainic ridge in the extreme southeastern part wells in some cases are sunk to a depth of 60 feet, mainly through till.

Along the southern border rock ledges appear in the bluffs of streams at 20 to 40 feet below the level of the bordering uplands, but wells usually obtain water without entering the rock.

SHELBY COUNTY.

General statement.—Shelby County is situated southeast of the center of the State, with Shelbyville as its county seat, and has an area of 400 square miles. The eastern part is more elevated than the western, but has a generally plane surface, the only morainic development being a small ridge in the southeast corner. The western part has a more diversified surface, produced in part by morainic ridges and in part by channels which were formed apparently prior to the deposition of the moraines and their associated gravel outwash, and which have been in part filled by the outwash from the moraines. The eleventh annual report of the State geologist contains a map which outlines the distribution of the several channels. The map is somewhat misleading in that it represents the island-like areas between these channels to be highland. The altitude is, in fact, only a few feet above the channels, seldom more than 25 feet, except in the case of a morainic ridge in the southwest part of the county, which has points standing fully 100 feet above the bordering channel. The full interpretation of the drainage history of this region has not been made, but it seems probable that considerable erosion of the drift plain had occurred during a retreat of the ice and that subsequently the ice invaded the western half of the county, blocking up portions of the channels, either by morainic accumulations or an outwash of gravel from the ice margin. In the vicinity of Fairland and to the northeast from that village the moraine graduates into a gravelly plain on its east border, and this gravelly plain slopes downward into one of the channels represented on the map accompanying the Indiana report. Well sections are given below, which show the amount of filling these channels have received by this outwash from the ice sheet. The morainic features on the west border of the county are of a strong type only in the southwest township, where the ice margin appears to have made an abrupt curve to the west. The sharp moraine was apparently formed because of this nose-like projection of the ice sheet.

The drift of the uplands in the eastern part of the county is composed largely of till and has a depth of 50 feet or more, if we may judge from outcrops of rock and occasional gas borings. The water wells are usually obtained without entering rock, there being beds of sand or gravel associated with the till. In the western part there appears to have been a preglacial basin with a rock surface much lower than that of the eastern portion of the county. This has been filled to a depth of perhaps 150 feet by the drift deposits, and the preglacial reliefs thus greatly obscured. The well sections given below will serve to illustrate the variability of the drift structure.

Individual wells.—Gas wells in the northwestern part of the county penetrate 150 to 200 feet of drift, of which the greater part is till.

The water wells of that region are usually obtained at depths of 15 to 50 feet, but occasionally reach a depth of 100 feet.

Wells on the gravel plain along East White River, above Shelbyville, have in several instances reached the bottom of the gravel and entered till at a depth of 25 or 30 feet.

The gravel plain along Brandywine Creek, east and northeast from Fairland, carries about 30 feet of gravel, beneath which is a sheet of till.

In Fairland the wells in the north part of the village penetrate 15 to 25 feet of till, at which depths they enter a water-bearing gravel. The southeast part of the village extends into the gravel plain, and wells there are obtained at similar depths without penetrating till.

Along Big Sugar Creek, west and southwest from Fairland, wells sometimes penetrate 50 or 60 feet of gravel without encountering till.

In an abandoned valley leading southward from East White River at Shelbyville to Lewis Creek and thence to Flat Rock, a valley which is generally termed the Slough, the gravel is 35 feet or more in depth and is underlain by till.

Along Flat Rock Creek, in the southern part of the county, wells are usually obtained at 10 to 20 feet.

On a morainic ridge near Mount Auburn, on J. M. Collins's farm, a well 108 feet in depth had the following section:

	Feet.
1. Sandy yellow till	20
2. Blue till	80
3. Sand and gravel	8
Total	108

Two other wells near Mount Auburn enter rock at 50 feet. On a plain north of Mount Auburn, known as "The Flat," in sections 4 and 9, Jackson Township, till is entered below gravel at a depth of 10 or 15 feet, and wells are in some cases obtained at 30 feet.

The following well sections of drift near Manilla are obtained from the eleventh report of the State geologist. Jacob Henry's well penetrates—

	Feet.
1. Soil	3
2. Loamy yellow clay	7
3. Loamy sand	10
4. Bowlder clay, blue	47
5. Fine quicksand	3
6. White sand	1
7. Gravel and sand	2
Total	73

The water rises within 1 foot of the surface.

On the adjoining farm of Arbuckle & Mills a well reaches a depth of 122 feet, penetrating—

	Feet.
1. Soil	2
2. Clay	33
3. Quicksand	3
4. Blue clay	5
5. Clay and gravel	2
6. Bowlder clay	17
7. Sand and gravel	3
8. Blue bowlder clay	57
Total	122

From the same report the following section of the boring on the farm of J. M. Collins, given above in somewhat different form, is obtained:

	Feet.
1. Soil	4
2. Yellow clay	6
3. Sandy clay	10
4. Bowlder clay	80
5. White sand	1
6. Sand and gravel	7
7. Limestone at bottom.	
Total	108

The bottom is estimated to be 50 feet below river level.

At Waldron, in the southeast part of the county, the drift is in places 80 feet in thickness, as shown by gas borings. A water well in the village is reported to have entered rock at 53 feet. It penetrates—

	Feet.
1. Yellow till	10
2. Sand and gravel	14
3. Gray till	28
4. Sand	1
5. Rock, thought to be sandstone	3
Total	56

At St. Paul the drift varies from 15 feet or less to nearly 100 feet in depth. The following depths are reported in gas-well borings: In No. 1, 17 feet; in No. 2, 87 feet; in No. 3, rock at surface; in No. 4, 16 feet; in No. 5, 23 feet. Water wells range in depth from 15 to 90 feet.

At Cynthi Ann, in the east part of the county, wells are usually obtained at 10 or 12 feet on level tracts, but on drift knolls in the village they reach a depth of 25 or 30 feet, and are mainly through till.

In the portion of the county northeast from Shelbyville wells range in depth from 10 to 50 feet or more, and are mainly through till.

Mention is made in the eleventh report of the State geologist of two wells in this county having water of exceptionally high temperature.

One in the east part of Shelbyville, 24 feet in depth, is reported to maintain a constant temperature, winter and summer, of 76° F. The other well, located 4 miles west of Shelbyville, is said to have increased in temperature after it was made, the water becoming too warm for drinking purposes, its temperature having reached 65° F. A pipe was driven in the bottom of the well to a depth of 16 feet, or 39 feet from the surface. The water was then found to have a temperature of 80°, and during that winter increased to 86° F. As these wells were excavated for potable water only, they have been filled.

JOHNSON COUNTY.

General statement.—Johnson County is situated in the south-central part of the State, with Franklin as its county seat, and has an area of 320 square miles. The greater part of the surface is plane, but there are morainic ridges of moderate strength traversing the county. One, which crosses the northern tier of townships from west to east, is known as the Greenwood moraine, the village of Greenwood being situated upon it. It is a belt but 1 to 2 miles in width, and has a relief of only 25 to 50 feet above bordering plane tracts. Another belt leads diagonally across the county from its northwest to its southeast corner, passing west and south of the city of Franklin. This moraine has a width of 2 to 5 miles, and varies greatly in strength. It is, on the whole, a less definite ridge than the one in the north part of the county. It has, however, numerous sharp knolls rising 25 to 40 feet, and occasionally 60 feet, above border tracts. From this morainic belt a small one leads off to the east just south of Franklin. It is scarcely a mile in average width, and has a relief of 20 to 40 feet. There is another moraine on the south border of the county, which is low and inconspicuous in the eastern part, but in the western part becomes a prominent, sharp ridge, with a relief of about 75 feet. This ridge, it is thought, belongs to the earlier ice invasion. The other moraines were formed during the later ice invasion. The southwestern part of the county appears to lie outside the limits of the later invasion.

The drift consists largely of a compact blue till, though the sharpest knolls are usually gravelly. There are gravelly plains in the southeastern part of the county, bordering the East White River, which are intimately associated with the morainic tract of that region as an outwash. In some cases deep wells have shown a large amount of sand or gravel in the lower part of the drift. The thickness of the drift probably averages 200 feet. A basin of Devonian shale which occupied the eastern and northern part of the county has been filled about to the level of the bordering rim on the southwest. The drift of the southwest part of the county is thinner than in the remainder, and wells occasionally enter the rock at depths of 20 to 60 feet. In the remainder of the county wells very rarely reach the rock. Water

is usually obtained at 40 feet or less in the dug wells and 40 to 100 feet in the tubular wells in beds of sand or gravel associated with the tills.

Individual wells.—At Greenwood, in the northern part of the county, the dug wells have a depth of but 12 to 30 feet. Tubular wells range in depth from 30 feet up to 100 feet or more. The best supply of water is obtained at 20 to 60 feet. A well at the Greenwood Sanitarium, 60 feet in depth, has sufficient head to bring the water nearly to the surface. Two wells at the fruit cannery have depths of 85 and 108 feet. The supply is from gravel a few feet in thickness in each well, but is inexhaustible. The village is making arrangements for waterworks supply from wells of this class. The Greenwood Sanitarium uses the water from two gas-well borings. The drift in these borings is 210 feet, and is largely till.

At Franklin the city water supply is obtained from driven wells 40 to 60 feet in depth. There is a small amount of surface gravel, but they are mainly through till. There are a few shallow wells 10 to 20 feet in depth obtained above the till. A well at the court-house is 80 feet, and several other wells in the city are 100 to 115 feet. Several flowing wells have been obtained in the north part of the city, on a tributary of Youngs Creek, at a depth of 40 to 45 feet. At the railway water tank in Hurricane Creek Valley a well obtains a flow of water at 30 feet. One flowing well in the southern part of the city is 90 feet in depth. Some of these wells cease to flow in dry weather. A gas-well boring in Franklin, 1,140 feet in depth, penetrates 170 feet of drift, as follows:

	Feet.
1. Till, yellow and blue	45
2. Sand	20
3. Blue till, with thin sand and gravel beds	105
Total	170

There is much water at 90 feet. There was also a flow of water from limestone at 205 to 210 feet. A well at the Baptist College, 114 feet in depth, penetrates—

	Feet.
1. Sand and gravel	18
2. Blue till	40
3. Fine sand	3
4. Blue till	50
5. Gravel	3
Total	114

Wells along the drift ridge south and east from Franklin usually penetrate 40 feet of till, beneath which water is obtained at a depth of 50 to 60 feet.

In the vicinity of Union Village wells are obtained at 30 to 75 feet in gravel beneath blue till.

A well on the slope of Donnell Mound, near Franklin, 40 feet above base, is mainly through gravel and sand to a depth of 50 feet.

A well at a schoolhouse in sec. 7, T. 12, R. 3 E., 95 feet in depth, penetrates 60 feet of drift, mainly till, beneath which is shale.

A well at Mr. Collins's, sec. 15, T. 13, R. 3 E., enters rock at 20 feet. A well at Mr. Wilkes's, section 14, in the same township, 40 feet in depth, does not reach rock.

At Williamsburg wells 20 to 50 feet in depth are mainly through blue till.

Wells in sec. 29, T. 11, R. 4 E., 20 to 40 feet in depth strike no rock. Wells in secs. 33 and 34, T. 11, R. 3 E., enter sandstone below till at about 20 feet.

Near Nineveh, in the southwest corner of the county, wells are 25 feet or more in depth, mainly in yellow till.

At Edinburg, in the southeast corner, wells are obtained at 25 to 60 feet, the usual depth being 30 to 40 feet. They are mainly through gravel; the city waterworks are supplied from such wells. At a gas boring in Edinburg 115 feet of drift was penetrated; the boring is 1,580 feet in depth. The salt water struck near the bottom rises within 80 feet of the surface.

MORGAN COUNTY.

General statement.—Morgan County is situated in the west-central portion of the State, with Martinsville as its county seat, and has an area of 430 square miles. Along the eastern and northern borders of the county the drift is heavy and the surface plane or but slightly hilly. In the central, southern, and western portions the surface is hilly and broken and the drift deposits thin. White River traverses this hilly district in a valley 1½ to 2 miles in width and 150 to 200 feet in depth. Its broad valley is filled with drift deposits to a depth of about 100 feet. Indian Creek, an eastern tributary entering near Martinsville, also has a broad valley deeply filled with drift.

The northern part of the county was covered by the ice at its later invasion, but the remainder appears to have been covered only at the earlier invasion. The glacial boundary is but a few miles south of the county limits, in northern Brown and northern Monroe counties. A prominent morainic ridge is found in this older drift, leading from Martinsville southeastward past Morgantown into Johnson County. Its relief in places is 75 to 100 feet, and being scarcely a mile in width, it is a conspicuous feature. This ridge, together with the remainder of the earlier drift sheet, is covered by a pebbleless clay or silt several feet in depth, which passes under the later sheet of drift. That sheet has till and bowlders at its surface.

On the elevated portions of the county there is seldom sufficient drift to afford water for wells. They are, therefore, sunk into the rock, and the depth varies considerably even in neighboring wells. Some are obtained at but 20 or 30 feet, while others are sunk to a

depth of 75 to 100 feet or more. On the lower parts of the county and along the valleys, the drift being heavy, wells are usually obtained without entering the rock, at moderate depths, seldom more than 40 feet. Occasional tubular wells, however, are sunk to depths of 75 to 100 feet or more.

Individual wells.—In the northwest part of the county there is a very level tract, known as "The Lake," which borders Mill Creek Valley, and extends eastward nearly to Monrovia. Wells on this plain are 10 to 30 feet in depth. They usually penetrate a few feet of sand at the top and beneath this a sheet of till before entering the water-bearing sand. Wood is sometimes found at the junction of the sand with the till.

At Monrovia wells usually obtain water at a depth of about 20 feet, in sand below till. One well, however, at David Miller's, near the public school building, is 118 feet in depth, mainly blue till. Wells on the border of the uplands, south and southwest of Monrovia, occasionally obtain water at 20 to 30 feet without entering rock. The majority, however, are sunk a short distance into the rock.

Wells on the morainic ridge east and southeast from Martinsville are in some cases 50 feet in depth. Some wells are largely through sand and gravel, others almost entirely through till.

At Morgantown, on the slope of the ridge, wells penetrate a surface clay and yellow till to a depth of 18 or 20 feet, beneath which there is often a blue till, though in some cases wells immediately enter a water-bearing gravel. Their depth ranges from 25 feet to 50 feet. Wells are obtained in drift for about 3 miles south from this village at depths of 30 feet or less.

In Martinsville the wells are usually dug to a depth of 20 or 30 feet through gravel. The city water supply is from a large well 30 feet in depth and 30 feet in diameter. There are a few flowing wells obtained in the northeast part of the city at depths of 40 to 75 feet. They penetrate a sheet of till below the surface sand and gravel. Several deep artesian wells have been sunk at this city, which furnish a soft sulphur water, which has a high reputation. Sanitariums have been built to accommodate the invalids who resort to these wells. Statistics concerning the wells and the character of the water are discussed elsewhere.[1]

OWEN COUNTY.

General statement.—Owen County is situated in the west-central part of the State, with Spencer as its county seat, and has an area of 390 square miles. The entire surface is hilly. In its eastern portion the hills are of limestone and in its western of sandstone. White River traverses its southeastern part in a valley very much narrower than the portion immediately above in Morgan County, the width being seldom so great as one-half mile. The highest parts of the

[1] Eighteenth Ann. Rept. U. S. Geol. Survey, Part IV, pp. 490-491, 498, 541.

uplands stand about 300 feet above the valley, but the immediate bluffs rise only 100 to 150 feet. The stream is in places in a new course and has its bed upon the rock, while in other places it is flowing on a drift filling 100 feet in depth. The drift deposits vary greatly in thickness, there being on many of the hills scarcely a trace of drift, while in one valley it has a known thickness of 250 feet. This county lies outside the limits of the later ice invasion, but it was almost entirely covered by the earlier invasion. Possibly the extreme southeast corner has escaped glaciation. The drift is variable in structure, some of the heaviest deposits being made up largely of gravel and sand, while neighboring localities are covered with an unmodified till. But little attention was given the depth of wells in this county, except at the three principal towns, Spencer, Gosport, and Quincy.

Individual wells.—At Spencer, the county seat, wells are obtained at various depths, ranging from 25 to 80 feet, with an average of perhaps 40 feet, at which depth they reach the level of the water in White River. Three artesian wells have been sunk at this city, descriptions of which, together with a water analysis, are presented in another report.[1] The drift at these wells is 90 to 97 feet in thickness.

Gosport is situated on the bluff of White River, and obtains wells at depths of 25 to 100 feet or more. Wells being difficult to obtain in some parts of the village, cistern water is substituted. An artesian well has been sunk in the valley to a depth of 926 feet, and obtains sulphur water similar to that at the neighboring cities of Martinsville and Spencer. No use is as yet made of the water, except by a few of the residents who prefer it to the hard water of the shallow wells.

The village of Quincy is situated in a lowland, probably an abandoned valley. The wells are 20 to 30 feet in depth, largely through a sandy drift. The water is said to stand within 5 to 10 feet of the surface.

Many springs are found along the bluffs in this county, which are utilized quite extensively by residents, and also resorted to by the stock.

CLAY COUNTY.

General statement.—Clay County is situated in the western part of the State, with Brazil as its county seat. Its area is 360 square miles. The greater part has a nearly plane surface, but the extreme eastern portion is hilly. The plane portion is underlain by the Coal Measures shales and soft sandstone, while the hilly portion is underlain by a hard sandstone. The drift is generally thin, rock being entered at the majority of the coal shafts within 20 feet of the surface. In the northern part of the county, however, the thickness is greater. There is probably also a deep filling along the valley of Eel River and also in other valleys. The drift is, in the main, a compact till, and in much of the county does not afford an adequate water supply. Wells

[1] Eighteenth Ann. Rept. U. S. Geol. Survey, Part IV, pp. 492, 499.

are therefore frequently drilled into the underlying Coal Measures strata, where an abundant supply is usually obtained at moderate depth—50 feet or less. There is a white clay or silt several feet thick covering the till throughout the county.

Individual wells.—At Perth, in the northern part of the county, wells are obtained in sandy beds between the yellow and blue till at a depth of about 15 feet. A boring for coal at this village penetrates 65 feet of drift, of which the lower 50 feet is till. A boring near this village in section 3 penetrates—

	Feet.
1. Surface clay	7
2. Sand and clay	8
3. Hard blue till	37
4. Sand and clay	11
5. Yellow till	4
Total	67

In a boring 80 rods north from the preceding the drift is 48 feet and consists of till, with the exception of 7 feet of sand at 30 to 37 feet.

At Carbon the drift is mainly till, and rock is usually struck at about 30 to 35 feet.

At Lena wells are usually 20 or 30 feet, mainly a hard blue till, and rock is not struck. A coal boring 1 mile west of Lena enters rock at 60 feet.

At Harmony the drift is about 30 feet in thickness, and wells are obtained near its base or in the upper part of the rock. At a coal shift between Knightsville and Harmony the drift is 60 feet in thickness.

At Knightsville the drift ranges in thickness from 12 feet up to about 50 feet. Wells are often obtained here at 12 to 20 feet in a sand below the surface clay.

At Brazil, the county seat, wells are usually obtained at about 20 feet, though they range in depth from 15 to 50 feet. The city waterworks are supplied from 8 driven wells, 20 feet in depth, the water being in a gravel beneath the surface clay. It is estimated that each well will yield 5,000 barrels per day. Rock is frequently struck in the vicinity of Brazil at about 20 feet, though there are several borings which penetrate 60 to 80 feet of drift. As a rule, the drift is a compact till.

In the central portion of the county the villages Asherville, Prairie City, and Saline City, obtain water in the upper part of the rock, the drift deposits being very thin, often less than 10 feet in depth. At Cory, in the west part of the county, the drift is about 40 feet, and wells are obtained without entering the rock.

At Bowling Green, in the eastern part of the county, wells enter a sandstone immediately below the soil and obtain water at various depths from 20 feet or less up to 60 feet or more.

In the southern part of the county, in the vicinity of Clay City, rock is usually entered at less than 20 feet and the majority of the wells obtain water near the surface of the rock.

VIGO COUNTY.

General statement.—Vigo County is situated on the west border of the State, with the city of Terre Haute as its county seat. It has an area of 410 square miles. The broad valley of the Wabash traverses its northwest part. This is bordered by a gravelly terrace nearly 5 miles in average width. West from the Wabash is a morainic belt, the continuation of the Shelbyville moraine of Illinois. This occupies perhaps half the upland on that side the river, and consists of a gently undulating or subdued morainic topography, with occasional sharp knolls 30 to 40 feet in height. The bordering uplands have a very plane surface. The moraine and the plain on the north lie within the limits of the Wisconsin or later drift, the moraine being the terminus of that drift. The uplands east of the Wabash are plane and are covered by the older drift sheet. This drift sheet is capped by a deposit of white clay several feet in thickness. On the immediate bluff of the Wabash, and in the northeastern part of the county, there are sand dunes, probably drifted by wind from the Wabash Valley.

The uplands west of the Wabash have drift varying in thickness from 10 feet or less up to more than 100 feet. The drift on the uplands east from the Wabash is generally but 20 to 40 feet in depth. It is probable, however, that tributaries of the Wabash, now obscured by the drift, have a filling of more than 200 feet. In the Wabash Valley borings at Terre Haute show a thickness of 150 feet of drift, the rock floor being nearly 100 feet below the bed of the present stream. Wells are usually obtained in the drift at depths of 20 to 40 feet or less, there being very few deep wells in the county.

Individual wells.—In the sand-covered tracts in the northeast part of the county coal shafts penetrate from 5 to 30 feet of sand, beneath which they are mainly through till to depths of 75 or 100 feet, where rock is entered. Wells are obtained either near the base of the sand or in beds of sand or gravel associated with the till. One well in Fontanet, 54 feet in depth, penetrates—

	Feet.
1. Sand	7
2. Clay and till	47
Total	54

A coal shaft 1 mile north of Fontanet penetrates 90 feet of drift, as follows:

	Feet.
1. Sand	28
2. Till	16
3. Sand	1
4. Till	39
5. Sand	6
Total	90

Another shaft near Fontanet, in section 12, has a similar section,

except that the lower sand bed is wanting. A third shaft in that vicinity penetrates 72 feet of drift, of which the upper 30 feet is sand and the remainder a solid bed of till. A shaft in the extreme northeast corner of the county, on Mr. Southard's land, penetrates 72 feet of drift, as follows:

	Feet.
1. Surface sand	20
2. Till	44
3. Sand	8
Total	72

At Terre Haute the use of private wells is considered unsafe and has been largely discontinued. Water may be obtained at about the level of the river at 30 to 50 feet, but there is no clay bed or impervious stratum of sufficient thickness to prevent contamination. The public water supply is obtained from the Wabash River above the city. Sanitary analyses of the hydrant water, and also of water from several private wells, are presented in another report.[1] The analyses show that a part of the water in each of the wells has been contaminated with organic matter.

Several borings for oil have been made within the limits of the city of Terre Haute which penetrate 100 to 150 feet of drift. In all these wells sand and gravel appear to extend from the surface to the bottom of the drift. These borings are discussed at some length in the Twenty-first Annual Report of the Indiana Survey.

A well near the brow of the Wabash bluff, south of Terre Haute, in sec. 32, T. 11, R. 9 W., penetrated the following interesting series:

	Feet.
1. Surface clay	5
2. Yellow sand	3
3. Fossiliferous loess	4
4. Soil and sandy peat	3
5. Bluish sandy subsoil	5
6. Yellow till	3
Total	23

A similar section was observed in the road grading immediately east of Terre Haute, at the east bluff of the Wabash.

A well in the upland, in sec. 20, T. 12, R. 8 W., strikes rock at 21 feet, and a shaft in the same section enters rock at 15 feet.

A well in sec. 32, T. 10, R. 9 W., enters sandstone at 22 feet, after penetrating the following beds:

	Feet.
1. Brown surface clay	5
2. Loess	2
3. Black soil	1
4. Brown till	14
Total	22

[1] Eighteenth Ann. Rept. U. S. Geol. Survey, Part IV, pp. 543-544.

Mr. Kester's well, sec. 20, T. 11, R. 9 W., penetrates 70 feet of drift, mainly till. A well in section 21 of the same township is mainly through sand and gravel to a depth of 63 feet and does not reach rock.

Wells on parts of the Wabash terrace, in the south part of the county, enter rock within a few feet, but the greater part of the terrace is underlain by a heavy bed of gravel and sand.

FRANKLIN COUNTY.

General statement.—Franklin County is situated on the east border of the State, near its southeast corner, with Brookville as the county seat. It has an area of 400 square miles. This county is traversed nearly centrally by the West and main Whitewater rivers and its northern portion is crossed by the east Whitewater, the junction of the East and West Forks being at Brookville. These valleys are 300 to 400 below the level of the bordering uplands; and yet gas-well borings in the vicinity of Brookville and Cedar Grove show a filling of 100 to 180 feet beneath the level of the present stream bed. Notwithstanding the great elevation of the uplands, the surface is plane over wide areas and the valleys are narrow. The northeastern part of the county lies within the limits of the later ice invasion. This invasion also touched the extreme northwest corner of the county. A small moraine was formed along the south border of the later sheet of drift, which, though only 30 or 40 feet in height, is readily traced, the bordering tracts being very plane as well as slightly lower. The moraine carries a few sharp gravelly knolls, but as a rule its surface is gently undulating. The older sheet of drift is covered with a deposit of white clay several feet in thickness, as in counties farther west and south, and the older drift here, as in other counties, is harder and more deeply oxidized than the newer drift.

The thickness of drift on the high uplands is often 10 feet or less, even within the limits of the later ice invasion. But it is probable that great amounts of drift are to be found in filled-up tributaries of the Whitewater system. Where rock is not entered within 10 or 15 feet of the surface the wells are usually obtained in the drift. This fact, together with the absence of gas-well borings or other prospect borings outside the limits of the Whitewater Valley, renders data concerning the thickness of drift rather meager.

Individual wells.—The city of Brookville obtains the supply for waterworks from two large open wells sunk in gravel, within 30 feet of the river channel, just above the city. The wells are sunk 12 feet below the lowest water in the river. They are excavated partly in sand and partly in rock, but the source of supply is by infiltration from the river. There are many cisterns and a few wells, both dug and driven, in use by the citizens of Brookville. The wells are sunk slightly below the level of the low-water stage in the river, a depth varying from 20 feet to 110 feet, according to elevation.

A boring at the brickyards in the south part of the city shows the ancient channel of the river to be about 180 feet below low water, or 440 feet above tide. Several other borings in the valley in the vicinity of Brookville enter rock at less depth. One near the junction of East and West Whitewater rivers penetrates 135 feet of drift, entering rock at about 495 feet above tide. Kimball's well, in Brookville, penetrates 160 feet of drift, but the rock surface here is no lower than at the well just mentioned. Bracken's well, in East Whitewater Valley, also enters rock at about the same level, after penetrating 135 feet of drift. A well at the poor farm enters rock at a similar elevation. A gas boring, 2 miles above Cedar Grove, penetrates 154 feet of drift and enters rock at about 450 feet above tide.

Wells at Fairfield, near East Whitewater, in the northern part of the county, in some instances reach a depth of 50 feet without entering rock, mainly through sand and gravel. Wells on the uplands between Fairfield and Laurel are usually obtained at about 20 feet. In the portion of the county east of East Whitewater rock is frequently entered at 10 to 20 feet, though a depth of 60 feet is occasionally reached without penetrating rock. Several sections were obtained on the plain between Little and Big Cedar creeks, east from Brookville, in which rock was entered at 8 to 20 feet.

At New Trenton, in the Whitewater Valley, wells on a terrace standing 80 or 90 feet above the river obtain water at about 90 feet. They are mainly through gravel.

At Metamora, in the West Whitewater Valley, wells are sunk about to river level, a depth of 30 feet.

Wells at Peppertown, on elevated upland, usually obtain water in sand below till at 20 or 25 feet.

Wells near Oldenburg enter rock at 40 feet or less, but water is sometimes found above the rock.

Several wells in Enochsburg strike rock at 20 feet or less, but water is obtained without penetrating far into the rock.

DECATUR COUNTY.

General statement.—Decatur County is situated in the southeastern part of the State, with Greensburg as the county seat. It has an area of 380 square miles. The county slopes gradually from northeast to southwest and drains mainly to the East White River. A narrow strip on the east border drains to Whitewater and to Laughery Creek. All except the eastern part of the county lies within the limits of the Wisconsin or later ice invasion, and a well-defined, though not conspicuous, moraine marks the limits of the drift of that invasion. It traverses the county from the northeast to the southwest corner, passing Greensburg on the east at McCoy Station. The extreme northwest corner of the county is also crossed by a moraine running parallel with the outer belt. These belts are each 2 or 3 miles or more in width, but

rise only 25 to 40 feet above the bordering plain and have a subdued expression. The sheet of older drift lying outside the limits of the newer drift may also be traced beneath the newer drift, numerous exposures of it being found along the streams in the vicinity of Greensburg. It is separated from the upper drift by both a soil and a pebbleless white clay such as covers the drift outside the moraine.

The thickness of the drift in this county is, as a rule, less than 50 feet, and at many places wells enter rock at 20 feet or less. The streams also are bordered quite extensively by rocky bluffs, although flowing usually in valleys but 25 to 50 feet in depth. It is probable, however, that preglacial valleys of great depth occur which have been completely filled. So far as the writer is aware, no wells or other borings have shown the position of such valleys. Very few records were obtained in which the drift exceeds or even approaches 100 feet. The drift is very largely composed of till, but there are sand and gravel deposits in sufficient amount to furnish water ordinarily at convenient depths.

Individual wells.—The thickest drift of which a section was obtained is that penetrated by a gas-well boring on the Robinson farm, north of Adams, in the northwest part of the county, where rock was struck at about 150 feet. The drift is as follows:

	Feet.
1. Till	19
2. Sand	4
3. Blue till	52
4. Gravel and sand	15
5. Yellow till	5
6. Oily blue clay, with few pebbles	16
7. Coarse gravel	15
8. Hard blue till	20
Total	146

In the village of Adams there are drift knolls 20 or 30 feet in height. Among these knolls rock is entered at 15 to 20 feet, but on the knolls wells are obtained without entering the rock.

At Greensburg, the county seat, shallow wells are obtained at 20 to 25 feet in drift. A few tubular wells obtain their supplies from near the bottom of the drift, at about 50 feet. The waterworks supply was at first obtained from driven wells 48 to 50 feet in depth, which reached the base of the drift and obtained their supply from a layer of gravel 4 or 5 feet thick. As the supply was inadequate in seasons of drought, a well 12 inches in diameter was drilled to a depth of 75 feet, penetrating the rock 25 feet. The main supply of water was struck at 21 feet in the stone. Probably two-thirds the population of Greensburg, or about 3,000 people, obtain their supply from this well, and in addition to this the Big Four Railway Company has a monthly consumption of 2,500,000 gallons.

In the vicinity of Clarksburg and Kingston, in the northeast part

of the county, on the moraine which marks the border of the later drift, wells are obtained at 20 to 40 feet in beds of sand or gravel associated with the till.

At Mechanicsburg, in the eastern part of the county, on the older drift, the wells are obtained at 15 or 20 feet without entering rock.

In the vicinity of Letts, on the moraine in the southwest part of the county, there are several deep tubular wells. One at Boyd's store obtains water from sand below till at a depth of 90 to 98 feet. A well at the tile factory, 117 feet in depth, does not strike rock. A well at H. Mitchell's, about 3 miles west of Letts, 101 feet in depth, enters rock at 80 feet. There is thought to be a buried soil at about 60 feet. Several wells about 2 miles west of Letts enter rock at 30 feet or less, on ground fully as elevated as at Mitchell's well.

At Newburg (Forest Hill post-office) wells are obtained at about 30 feet without entering rock. Wells along a valley west from this village obtain water at a depth of 10 feet.

At Westport, on the south slope of the outer moraine of the later drift, wells in some cases enter rock at about 30 feet, but many obtain water in the drift.

At Sardinia, also near the border of the moraine, wells enter rock at 25 to 35 feet.

BARTHOLOMEW COUNTY.

General statement.—Bartholomew County is situated in the south central part of the State, with Columbus as the county seat, and has an area of 400 square miles. East White River passes through the county from north to south, slightly west of its center, following the axis of a trough or basin in the Devonian shale. There is a gradual westward descent from the east border of the county to the river valley. West from the river there is a low plain, rising gradually westward to the border of the county, where a range of prominent Knobstone hills sets in, which rises several hundred feet above the basin.

The entire county was apparently glaciated, although the glacial boundary lies but little west from the front of the prominent hills on the county line. The portion of the county east from the East White River Valley was nearly all covered by the later ice invasion, and a narrow belt along the west side of the stream in the north part of the county was also covered by that invasion. There remains, therefore, only a narrow strip on the southern and western borders of the county where the older sheet of drift alone is present. There are morainic features along the borders of the East White Valley from the north line of the county southward to the vicinity of Columbus. There are also two well-defined moraines leading eastward and northeastward from this valley across the county. The southernmost one, which lies near the line of Bartholomew and Jennings counties, marks the southern limit of the later or Wisconsin sheet of drift. The other

lies near the borders of Clifty Creek. Each of these moraines has a breadth of 2 or 3 miles, but they stand only 20 to 40 feet above the bordering plain. The surface of the older drift in this county is generally plane. The thickness of the drift ranges from a mere trace to a deposit fully 100 feet in depth. Along the East White Valley there is a gravelly belt 3 to 5 miles or more in width, and the morainic knolls just referred to appear in the midst of this gravelly district. Flat Rock Valley also contains a broad gravel plain. In the remainder of the county the drift is mainly till. Very few deep wells occur, there being generally an abundant water supply within 35 or 40 feet of the surface.

Individual wells.—At Columbus the gas-well borings penetrate about 100 feet of drift, mainly gravel, in which large amounts of water occur from a depth of 30 feet downward. The waterworks supply is from the East White River, and the greater part of the population are dependent upon it. The few private wells in use have a depth of about 30 feet.

On the gravel plain south from Columbus, in the vicinity of Wailesboro and Jonesville, wells are obtained at 20 or 30 feet, or at about the level of the water in East White River.

On the low land west of East White River wells ordinarily penetrate 8 or 10 feet of pebbleless clay, beneath which they enter till. Water is usually obtained at 20 feet or less in beds of gravel associated with the till.

The record of a well was obtained on a prominent part of the Knobstone ridge near the west border of the county in sec. 18, T. 9, R. 5 E., which reached a depth of 38 feet without entering rock. Wells often enter rock on this high land, however, at 10 or 15 feet. The well referred to has the following section:

	Feet.
1. Surface silt	8
2. Sandy material	5
3. Brown till	5
4. Blue till	20
Total	38

At a schoolhouse near this well water was obtained at only 20 feet, in a bed of sand below the surface silt.

A well near the base of the high upland, in sec. 29, T. 10, R. 5 E., 56 feet in depth, enters rock near bottom.

Records of several wells were obtained in the eastern part of the county which have a depth of 30 to 38 feet without entering rock. They are mainly through a soft till of the later ice invasion.

On the gravel plain along Flat Rock Creek, in the north part of the county, wells are usually obtained at a depth of 10 to 20 feet, or about the level of the stream.

JACKSON COUNTY.

General statement.—Jackson County is situated in the southern part of the State, with Brownstown as the county seat, and has an area of 510 square miles. East White River traverses it nearly centrally from northeast to southwest, and Muscatatuck River forms much of its south boundary. The western one-third of the county is elevated and largely unglaciated. The eastern part is mainly a low plain, though there are occasional knobs rising to heights of 200 feet or more above the plain. There is also a sharp drift ridge, 50 to 170 feet in height, leading southward from near Seymour to the vicinity of Mount Sidney. This drift ridge has a breadth of less than a mile, and is in consequence a very conspicuous feature. It is known as Chestnut Ridge, and several well sections along it are presented below.

In the eastern part of the county, between the two forks of the Muscatatuck, the drift deposits are thin, as in neighboring counties on the east, seldom reaching a depth of 50 feet; but in the district between the Muscatatuck and East White River, which includes Chestnut Ridge, the general thickness of drift is probably 100 feet, while on the ridge it may exceed 200 feet. The greater part of the drift is of a sandy constitution, though deposits of till and gravel are known to occur both in the ridge and on the bordering plain. In the southern part of the county, near the Muscatatuck, a compact clay, containing very few pebbles, constitutes the upper portion of the drift.

Individual wells.—No detailed records of wells were obtained in the unglaciated western portion of the county, but it is known that the depth there is variable, some wells being obtained at 20 feet or less, while others are 75 to 100 feet.

At Brownstown, the county seat, wells are usually about 20 feet in depth. In some instances they are obtained in the sand, but in others they enter shale a few feet.

At Seymour wells range in depth from 15 to 50 feet, and are usually driven through sand and sandy clay. The greater part of the water supply is furnished by the waterworks, and is pumped from East White River.

A gas-well boring in the northeast part of Seymour penetrates 75 feet of drift, as follows:

	Feet.
1. Coarse sand	12
2. Very fine sand or silt, almost a clay	43
3. Black muck, probably an old flood plain of the river	10
4. Coarse sand with large amount of water	5
5. Blue clay	5
Total	75

The black muck of this section is found quite widely in the vicinity of Seymour at a nearly uniform elevation. The thickness of the drift in the vicinity of Seymour ranges from 70 feet to 90 feet.

On the plain bordering Chestnut Ridge, south from Seymour, wells are usually obtained at a depth of 30 feet or less, though a few reach 40 feet. They are mainly through fine sand or clay, yellow at top, but of blue color at a depth of 16 to 18 feet. A flowing well on this plain is reported by Professor Cox to obtain water in a soapstone shale beneath alluvium and drift at a depth of 27 feet. The well is located on a branch of Pond Creek, in sec. 7, T. 4, R. 5 E., a few feet below the general level of the plain.

The following sections of wells were obtained on Chestnut Ridge. Harvey Morris's well, near the north end of the ridge, 89 feet in depth, penetrates—

	Feet.
1. Clay containing a few pebbles in lower part	20
2. Fine sand, becoming gravelly near bottom	69
Total	89

Jerry Anderson's well, also near north end of ridge, 95 feet in depth, penetrates—

	Feet.
1. Clay, pebbleless at surface, but quite pebbly below, and assuming a blue color in lower part	52
2. Gray sand too fine to screen, but yielding water	38
3. Gravel	5
Total	95

Hiram Love's well, 57 feet in depth, penetrates—

	Feet.
1. Surface clay and yellow till	20
2. Blue till	30
3. Gravel and sand	7
Total	57

A well at Mr. Wieneke's, on the highest point of the ridge, 77 feet in depth, penetrates—

	Feet.
1. Sandy loam	15
2. Loose sand	18
3. Reddish gravel and sand with clay admixture, probably till	40
4. Coarse gravel	4
Total	77

A strong spring gushes out of the slope of the moraine west of Mr. Wieneke's residence at about the level of the bottom of the well and probably from the same gravel bed. At M. T. Cox's residence, on a low part of the ridge, scarcely 50 feet above the bordering plain, a well 107 feet in depth penetrates—

	Feet.
1. Till	50
2. Fine sand	25
3. Gravelly sand	32
Total	107

Wells in Dudleytown, also on a low part of the ridge, obtain an abundance of water at less than 50 feet. Henry King's well, on the slope of the ridge south from Dudleytown, perhaps 30 feet above the level of the border plain, reaches a depth of 63 feet. John W. Collin's well, near the south end of the ridge, at an altitude nearly 100 feet above the plain, obtains water at 50 feet. A log was penetrated near the bottom in a sandy blue clay.

In the vicinity of Mount Sidney, on the borders of the Muscatatuck River, wells are obtained at 40 to 45 feet in sand and gravel below till. The water bed is apparently a little higher than the level of the river.

SCOTT COUNTY.

General statement.—Scott County is situated southeast of Jackson County, in the southern part of the State, with Scottsburg as its county seat. It has an area of but 190 square miles. The greater part of the county is a low plain lying along the eastern base of the Knobstone escarpment and underlain by Devonian shales. The eastern and southeastern parts, however, are more elevated and are underlain by limestone. The greater part of the county has been glaciated, but the drift deposits are usually only a few feet in thickness, rock being entered as a rule at 20 feet or less. In the north part of the county, however, on the borders of the Muscatatuck there is at least 50 feet of drift.

Individual wells.—At Scottsburg, the county seat, wells are usually obtained at 25 to 35 feet or less. The drift is about 50 feet. A gas-well boring near the railway station penetrates 47 feet of drift, as follows:

	Feet.
1. A yellowish white clay, nearly pebbleless	15
2. Sand	5
3. Blue till	27
Total	47

A boring at the fair ground, a mile southeast from Scottsburg, entered rock at 40 feet. It encountered much wood in a blue till in its lower part.

At Little York, near the west line of the county, wells usually enter shale at 15 or 20 feet, and obtain water at depths of 25 to 45 feet. Within a mile east from Little York a thicker drift sets in and wells are obtained without entering the rock at depths of 25 feet or less.

At Vienna, a well at the canning factory enters rock at 12 feet and obtains water at about 30 feet.

At Summit, or Underwood Station, near the south line of the county, wells usually enter shale at about 8 feet and obtain water at 20 to 30 feet. A well at Mr. Hosea's, one-half mile west of this village, 40 feet in depth, enters shale at 25 feet, but its water supply is from gravel at from 12 to 25 feet.

At Lexington, in the east part of the county, wells enter limestone within a few feet of the surface and obtain water at depths of 20 to 30 feet or less.

LIMESTONE DISTRICT OF SOUTHEASTERN INDIANA.[1]

General statement.—This district embraces Dearborn, Ohio, Switzerland, Ripley, Jefferson, and Jennings counties and the east part of Scott and Clark counties, an area of about 2,000 square miles. It is bordered on the southeast by the Ohio River from Lawrenceburg to Jeffersonville, Indiana.

The entire district has been glaciated, though lying entirely outside the limits of the later ice invasion, if we except a few square miles along the north border of Jennings County. On the higher parts of the upland the drift is usually but 10 to 20 feet in thickness, and is covered with a deposit of white clay nearly free from pebbles, having an average thickness of about 5 feet. The valleys and lowlands are usually filled quite deeply with drift deposits, especially in the case of the larger streams, which are as a rule occupying preglacial valleys. It is not rare to find in these valleys a drift filling to a height of 150 feet above the present beds, and the deposits, if we may judge from the depth of drift along the Ohio, probably extend 75 to 100 feet below the present streams. The drift on the uplands consists mainly of a compact clay, and strong wells are seldom obtained from this deposit. Beneath this clay there are frequently beds of black soil, which in some cases appear to be of interglacial and in other cases possibly of preglacial age. Those thought to be of interglacial age are underlain by sandy deposits, probably due, directly or indirectly, to the ice invasion. There are others which rest upon the rock strata or residuary clay, and these may be of preglacial age. Several instances of the occurrence of such soils are presented in the reports of the Indiana geological survey. In valleys the drift is often, if not generally, composed largely of sand and gravel, but has bowlders and cobble stones mixed with the finer material.

Individual wells.—The data concerning the wells here reported were obtained chiefly from the water-supply schedules sent out to various cities and villages in the district. A few were obtained while in field work, and a few are taken from the reports of the Indiana geological survey.

Along the Ohio Valley wells are usually obtained at about the level of the Ohio River at its low-water stage. The terraces are in some places fully 100 feet above the river, and wells 100 feet in depth on such terraces are not infrequent. They penetrate usually a gravel of medium coarseness, interbedded with fine gravel or sand. In places the deposits are cemented, but this feature is not a common one. The towns are taken in order from Lawrenceburg down the valley.

Lawrenceburg stands on a gravel terrace 80 to 85 feet above the low water of the Ohio, or about 505 to 510 feet above tide. The drift at

this point is shown by gas borings to be about 140 feet, reaching a level 55 or 60 feet below the low water of the Ohio. It is composed largely of gravel, and an abundance of water may be obtained by driving pipes to the level of the river. Professor Orton calls attention, in the Geology of Ohio, to an exposure of a clayey bed near the low-water level which carries timber of several kinds. This is thought to be an old flood plain of the river. Concerning it Professor Orton remarked, "It is perhaps too early to write out this history in its minuter features, but the facts already given show us that we have in this sheet of blackened clay the bottom lands of the Ohio Valley of an earlier day, and, indeed, under very different conditions from those that now prevail. The river then ran in a channel lower by 40 feet at least than that which it now holds, and the great valley was then empty of the immense accumulations of sand, clay, loam, and gravel which constitute its bottom lands and terraces to-day."[1] A similar blackened clay has been noted at several points below Lawrenceburg, near the level of low water.

At Aurora a gas boring shows the drift to be 92 feet in depth on ground standing only 45 to 50 feet above the low water of the river. The wells in this city usually obtained water at about 50 feet near the level of low water of the river.

Rising Sun is situated on a terrace standing about 110 feet above the river in its highest part, but the town extends down the slope to a level only 60 feet above the river. Wells at the level of the top of the terrace have, in some instances, been sunk to the level of the river, one well at Cornelius Harris's being 114 feet and one at J. M. Pate's 112 feet in depth. Mr. Pate's well obtained some water at 27 feet, and weak wells are often obtained at about that level on the terrace. The drift at Mr. Pate's well is mainly sand, but a bed of blue mud was passed through at about 50 or 60 feet. A well at an old mill on the river bank 120 feet in depth reached a level 60 feet below the low water of the river without encountering rock. Only a half mile above the mill, on the Kentucky side, rock extends half way across the river channel at level of low water.

At Vevay wells are usually obtained at a depth of 60 to 80 feet, but occasionally reach a depth of 100 feet. The terrace on which the main part of the town stands is about 80 feet above low water. It is composed largely of fine gravel, which is cemented in places at depths of 20 to 50 feet. The supply for the waterworks at Vevay is pumped from the Ohio River.

At Carrollton, Kentucky, 8 miles below Vevay, Mr. J. F. Jett made a boring at his distillery, near the mouth of the Kentucky River, 107 feet in depth, which reaches a level 50 feet below the low water of the Ohio, without striking rock. The boring was stopped in a cemented gravel.

At the city of Madison, Indiana, several wells on a terrace standing

[1] Geol. Ohio, Vol. I, p. 429.

90 to 100 feet above the river have reached a depth of 120 feet without entering rock. The terrace in the eastern portion of the city is underlain by a coarse gravel, but in the western portion the drift becomes sandy. The waterworks obtain a large part of the supply from the Ohio River by infiltration into a large well excavated at the side of the river. A portion of the supply is from springs in the west part of the city. Probably half of the population still depend upon private wells and cisterns, there being only about 1,200 private connections with the waterworks in a population of 10,000.

At Jeffersonville wells are obtained at a depth of 40 or 50 feet in sand and gravel, water being found at about the low-water level of the river above the Louisville rapids. A few drilled wells enter the hydraulic limestone 8 to 12 feet. This limestone is struck in portions of the city just below the level of low water.

Statistics concerning wells were obtained at several villages on the uplands in these southeastern counties of Indiana, as follows: At Versailles, the county seat of Ripley County, wells are obtained at depths of 18 to 25 feet in the upper part of the limestone. At Osgood wells are usually obtained near the base of the drift at depths of 9 to 15 feet. Occasionally wells are drilled to a depth of 100 feet or more in the northern part of Ripley County. At North Vernon, in Jennings County, wells are obtained at depths of 12 to 35 feet, the majority being about 25 feet. They usually enter the rock a few feet. The waterworks obtain a supply from the Muscatatuck River. The village of Vernon also obtains its waterworks supply from the Muscatatuck River. At Charlestown, formerly the county seat of Clark County, wells are obtained at a depth of 30 to 35 feet, usually in the Corniferous limestone. A few, however, reach this depth without entering rock. In wells where drift 25 to 30 feet in thickness is penetrated it is quite common to find a blue mud carrying tree trunks or small pieces of wood near the base of the drift. Rock is ordinarily struck in this village at about 12 feet. There are four very strong springs within the corporate limits of the town, which are made use of by many of the residents.

The following sections of wells on the uplands, taken from the reports of the Indiana Geological Survey, are of interest in showing the presence of a buried soil. Mr. N. Van Osdel's well, in the broken upland of Ohio County, sec. 6, T. 3, R. 2 W., penetrates—

	Feet.
1. Soil and clay	22
2. Yellow sand, quite hard or cemented	9
3. Blue clay, hard, without pebbles	1½
4. Black soil containing rotten leaves, twigs, and wood, thought to be walnut	1½
5. Coarse sand, gravel, and shelly stone	9
6. Hard blue limestone	1
Total	44

At Mr. J. B. Gordon's, sec. 4, T. 5, R. 12 E., in the northwest part of Switzerland County, a well penetrates—

	Feet.
1. Soil and clay, pale in lower part	22
2. Blue mud resembling recent alluvium	6
3. Black soil, containing leaves, cedar wood, and ocherous particles	3
4. Small stones closely packed together	1
Total	32

It is thought that the bottom bed in this well is native rock. A neighboring well struck leaves and poplar bark at 32 feet. Wells in that vicinity often enter rock at 10 to 14 feet. In the vicinity of Paris Crossing, in the extreme southern part of Jennings County, buried timber is often found in digging wells on land 60 to 70 feet above the bed of Graham Creek. In one well sunk by Mr. John F. Files it is estimated that at least a half cord of wood was taken from a well at a depth of 32 to 40 feet. The wood appears to be birch, and specimens were sent to the State museum. The wood is much crushed and twisted, but it was found suitable for fuel and was thus made use of by Mr. Files. The following is the section of the beds penetrated—

	Feet.
1. Light-colored clay with darker shades below	10
2. Ocher-colored clay with flint pebbles, increasing in hardness toward the bottom	19
3. Very hard bed of clay and gravel	2 to 3
4. Sandy blue clay, with water; also limbs, twigs, and roots of trees	7 to 10
Total	38 to 42

The ingress of water prevented the deepening of the well, and the wall was commenced on the driftwood at its bottom. A well at South Milan, in eastern Ripley County, 54 feet in depth, did not enter rock, though quarries are opened in that vicinity at about the level of the well mouth. The following is a section of the well made by the railway company:

	Feet.
1. Light-colored clay	10 to 14
2. Yellow clay, with flint, gravel, and fossil corals	12
3. Blue glacial clay	12
4. Coarse yellow sand, with recent shells and water	8
5. Blue clay and muck, containing roots and limbs of trees	8
Total	54

KNOBSTONE BELT OF SOUTHERN INDIANA.

The portion of this belt outside the drift border covers the greater part of Brown and Jackson counties, western Bartholomew, northeastern Washington, western Scott, western Clark, and a narrow strip in Floyd and Harrison counties, an area of about 1,200 square miles. Its ridges stand 800 to 1,150 feet above tide and comprise the highest land in that part of the State. The writer is personally

acquainted with but a small part of this belt and has found but few published data bearing upon its capacity for supplying wells. In the roughest portions agriculture is carried on with difficulty, and the few residents depend largely upon cisterns and springs; but in the less rugged and more thickly settled portions wells are said to be in use. Nothing has been learned to indicate that difficulty is experienced in obtaining water of good quality at convenient depths. The few wells reported show an average depth of but 20 to 30 feet.

LIMESTONE BELT OF SOUTHERN INDIANA.

The portion of this belt outside the drift border covers the greater part of Monroe, Lawrence, Washington, Orange, and Harrison counties, also western Floyd and eastern Crawford counties, a combined area of about 2,000 square miles. This limestone belt has generally an abundance of good water within 50 feet of the surface, and good wells 30 feet in depth are not rare. In a few cases wells have been sunk to depths of 100 to 150 feet, with a view to increasing the amount of water. However, the few data at hand seem to indicate that the chances for obtaining fresh water in the upper 100 feet are better than at lower depths. The early settlers made open wells, but in recent years drilled wells are coming into use. The latter are sunk to a greater average depth than the former, but are seldom more than 100 feet. The extreme hardness of the water is also objectionable and has led to extensive use of rain water collected in cisterns.

Some of the strong sulpho-saline wells and springs of southern Indiana which have gained wide reputation for medicinal properties are obtained in this limestone. There are many salt and sulphur springs which have never been brought to public notice on account of their difficult accessibility or other adverse conditions. Some wells and springs were used in the manufacture of salt, on a small scale, in the early days of settlement, before the great salt industries of the neighboring States were developed. Salt Creek, one of the main tributaries of East White River, receives its name from springs of salt water found on its middle and lower courses.

CONGLOMERATE SANDSTONE OF SOUTHERN INDIANA.

This sandstone forms a narrow belt along the west border of the limestone, its average width of outcrop being scarcely 10 miles. Like the Knobstone belt, it is characterized by sharp ridges and hills, which are but sparsely settled, agriculture being carried on with difficulty. The water afforded by springs, together with cistern water collected from roofs of dwellings, often supply the needs of the residents. Wells are apparently less common than in the limestone district on the east, and are far less numerous than in the Coal Measures basin that borders it on the west. The few available data concerning wells in this sandstone indicate that a fair supply of water may be obtained at convenient depths.

COAL MEASURES BASIN OF SOUTHWESTERN INDIANA.

Under this head is included the portion of western Indiana south from Vigo, Clay, and Owen counties covered by the Coal Measures sandstone and shale, an area of about 4,500 square miles. Fully two-thirds of this region has a thin coating of drift. The remainder is driftless, except a coating of loess.

The loess seldom affords a supply of water for wells, as it is usually but 5 to 10 feet in depth. The glacial drift may be depended upon in perhaps half its extent in this region to supply a sufficient amount of good water for the needs of the residents. Where it exceeds 20 feet in depth there is usually present a water-bearing bed which will supply wells for household use. Occasionally wells strong enough to supply the stock on a farm are obtained from drift deposits, but the strong wells are usually obtained from the rock. Along the Wabash Valley, however, strong wells are generally obtained in glacial deposits at shallow depths, there being a heavy deposit of water-bearing gravel in the valley.

Along the Ohio Valley above Mount Vernon there are extensive bottom lands, in which a compact clay must be penetrated 60, 80, and occasionally 100 feet or more before water-bearing sand or gravel is reached. Similar bottoms occur in Evansville and just above the city. Farther east, between Yankeetown and Rockport, wide bottoms are underlain by sand, in which wells are obtained at depths of but 20 to 40 feet. Many of these wells overflow and afford excellent water.

Where wells are not obtained in the drift they are usually obtained in the underlying rock at convenient depths—30 to 60 feet, or less. The wells in the driftless portion also usually obtain water at convenient depths. The water in these shallow wells in rock is in some localities objectionable because of sulphates, and is known as "copperas water," but the great majority of wells yield water of pleasant taste and harmless quality.

A few wells have been sunk to depths of 200 feet or more which obtained fresh water. Coal shafts also have in some cases struck fresh water at similar depth. The chances, however, are against obtaining fresh or potable water from such depths, and the residents usually make use of large cisterns if water can not be obtained in suitable amount from shallow wells.

INDEX TO PLACES.

	Page.
Adams	50
Alamo	18
Alexandria	11
Allisonville	28
Alquina	35
Amo	26
Anderson	11-12
Annapolis	22
Arlington	36
Asherville	45
Attica	19-20
Aurora	57
Bainbridge	25
Bartholomew County	51-52, 59-60
Bechy Mire	34
Bellmore	23
Bloomingdale	23
Boone County	13-17
Bowling Green	45
Brazil	45
Bridgeport	28
Brightwood	27
Brookville	48-49
Brown County	59-60
Brownsburg	26
Brownstown	53
Brownsville	34
Cadiz	31
Cambridge City	33
Carbon	45
Carmel	13
Carrollton, Ky	57
Carthage	36
Castleton	28
Cayuga	21
Cedar Grove	49
Centerville	33
Chambersburg	20
Charlestown	58
Cicero	13
Clark County	56-60
Clarksburg	50-51
Clarksville	13
Clay City	45
Clay County	44-45
Clayton	26
Clinton	21
Coatsville	26
Columbus	52
Connersville	35
Cory	45
Covington	20
Crawford County	60
Crawfordsville	18-19
Cumberland	27
Cynthi Ann	39
Daleville	10
Dalton	33
Danville	26
Dearborn County	56
Decatur County	49-51
Delaware County	9-10
Dudleytown	55
Dunreith	31
Eagletown	13
Eaton	10
Edinburg	42
Elizaville	15
Elwood	11
Enochsburg	49
Eugene	21
Evansville	61
Fairfield	49
Fairland	38
Farmland	8
Fayette County	34-35
Fincastle	25
Fishers Station	13
Floyd County	59-60
Fontanet	46-47
Forest Hill	51
Fountain City	32
Fountain County	19-20
Franklin	41, 42
Franklin County	48-49
Frankton	12
Glenwood	36
Gosport	44
Greenfield	29
Greensboro	31
Greensburg	50
Greenwood	41
Hagerstown	32
Hamilton County	12-13
Hamilton Station	36
Hancock County	29
Harmony	45
Harrison County	59-60
Hendricks County	25-26
Henry County	29-31
Homer	36
Honeycreek Station	31
Howard	23
Huntsville	12
Indianapolis	27-28
Irvington	27
Jackson County	53-55, 59-60
Jackson Township	24
Jackson Township	38
Jamestown	16, 17
Jefferson County	56-59
Jeffersonville	58
Jennings County	56-59
Johnson County	40-42
Jolietville	13
Jonesville	52
Kennard	31
Kingston	50-51
Knightstown	31
Knightsville	45
Laurel	49
Lawrence	27
Lawrence County	60
Lawrenceburg	56-57
Lebanon	15-17
Lena	45
Letts	51
Lewisville	31
Lexington	56
Liberty	34
Little York	55
Lizton	26
Lodi	20
Lodi	23
Losantville	9
Lotus	34
Luray	30
Lynn	9
McCordsville	29
Madison	57-58
Madison County	10-12
Manilla	38-39
Marion County	26-28
Markleville	12
Marshall	23
Martinsville	43, 44

	Page.
Mechanicsburg	51
Metamora	49
Middletown	31
Mill Creek Township	20
Milledgeville	17
Monroe County	60
Monrovia	43
Montezuma	23
Montgomery County	18–19
Moreland	30
Morgan County	42–43
Morgantown	43
Mount Auburn	38
Mount Sidney	55
Mount Summit	30
Mount Vernon	61
Muncie	10
New Brunswick	17
New Palestine	29
New Salem	36
New Trenton	49
Newburg	51
Newcastle	30
Newtown	21
Nineveh	42
Noblesville	12–13
North Salem	25–26
North Vernon	58
Northfield	15
Oakland	27
Ogden	31
Ohio County	56
Oldenburg	49
Orange County	60
Osgood	58
Owen County	43–44
Paris Crossing	50
Parke County	21–24
Parker	8
Pendleton	12
Peppertown	49
Perth	45
Philadelphia	29
Plainfield	26
Pleasant Hill	18
Posey County	61
Prairie City	45
Putnam County	24–25
Quincy	44
Raleigh	36
Randolph County	7–9
Ratsburg	16
Reno	26
Richmond	32, 33
Ridgeville	8
Ripley County	56–59
Rising Sun	57
Rockport	61
Rockville	23
Rosedale	23–24
Roston	16
Royalton	17
Rush County	35–36
Rushville	36
St. Paul	39
Saline City	45
Sardinia	51
Scott County	55–60
Scottsburg	55
Selma	10
Seymour	53
Shelby County	37–40
Shelbyville	38, 39–40
Sheridan	13
Shideler	10
Slabtown	15
South Milan	59
Spencer	44
Spencer County	61
Spiceland	31
Springport	30
Stone Bluff	20
Sulphur Springs	31
Summit	55
Summitville	10
Switzerland County	56
Terre Haute	47
Thorntown	14, 15
Underwood Station	55
Union Church	14
Union City	8
Union County	33, 34
Union Village	41
Vanderburg County	61
Veedersburg	20
Vermilion County	20–21
Vernon	58
Versailles	58
Vevay	57
Vienna	55
Vigo County	46–48
Wallesboro	52
Waldron	39
Walnut Level	33
Warrick County	61
Washington	33
Washington County	59, 60
Wayland	19
Wayne County	31, 33
West Union	23
Westfield	13
Westport	51
Wheeling	10
Williamsburg	32
Williamsburg	42
Winchester	8
Windsor	9
Yankeetown	61
Zionsville	17

55TH CONGRESS, 3d Session. } HOUSE OF REPRESENTATIVES. { DOCUMENT No. 297.

DEPARTMENT OF THE INTERIOR

WATER-SUPPLY

AND

IRRIGATION PAPERS

OF THE

UNITED STATES GEOLOGICAL SURVEY

No. 27

OPERATIONS AT RIVER STATIONS, 1898.—PART I

WASHINGTON
GOVERNMENT PRINTING OFFICE
1899

CONTENTS.

	Page.
Letter of transmittal	6
Introduction	7
Northern Atlantic coast drainage	9
Southern Atlantic coast drainage	25
Eastern Gulf drainage	47
Ohio River drainage	59
Great Lakes drainage	66
Upper Missouri River drainage	68
Platte River drainage	76
Kansas River drainage	89
Conversion tables	96

LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF HYDROGRAPHY,
Washington, March 1, 1899.

SIR: I have the honor to transmit herewith a manuscript giving the results of operations at the river stations in the eastern and central portions of the country during the calendar year 1898, together with related data, for publication in the series of papers upon water supply and irrigation. The data for the western portion of the country (Part II) will be transmitted as the succeeding number of the series.

Very respectfully,

F. H. NEWELL,
Hydrographer in Charge.

Hon. CHARLES D. WALCOTT,
Director United States Geologicaal Survey.

OPERATIONS AT RIVER STATIONS, 1898,

PART I.

INTRODUCTION.

The following pages contain descriptions of the river stations maintained during 1898 by the United States Geological Survey, together with tables of the average daily height of water, results of measurements of discharge, and rating tables constructed from the latter and applicable in general for the calendar year. Similar facts have been printed for the year 1896 in Water-Supply Paper No. 11, and for 1897 in Water-Supply Papers Nos. 15 and 16. In the papers mentioned the description of each station has been given, next the date and result of each measurement, followed by the table of daily gage heights. In the present manuscript the order has been modified in order to secure a more concise presentation. The stations have been grouped in geographic order, and for each group the descriptions of all of the stations have been given; following these all of the gage heights for the group, then all of the discharge measurements and the rating tables. In the case of river stations, where the changes have been trivial in character, the descriptions have not been repeated, but reference made to the page of preceding papers where more fully described.

The material above noted consists essentially of the results of operations at the river stations, and forms the basis for computations of daily, monthly, and annual flow. In order to make these necessary computations considerable time and labor is involved and the resulting facts can be most clearly and concisely given by diagrams. The preparation of the computations and the diagrams necessitates unavoidable delays, and therefore it has been the custom to present the facts, such as are given herewith, as soon as possible after the close of the calendar year, so that the original data may be available at an early date to all who are concerned with their use. While these original figures are being printed the computations of final results are being prepared, and, with the illustrations, have in the past been made to form a part of the annual report of the Director of the Geological Survey. For example, the results for 1896, mentioned above, as given in Water-Supply Paper No. 11, are fully discussed in Part IV of the Eighteenth Annual Report, also the original data for

1897, given in Water-Supply Papers Nos. 15 and 16, are published in final form in the Nineteenth Annual Report, Part IV. In the same way the figures herewith given form the basis for conclusions, being prepared for publication in Part IV of the Twentieth Annual Report.

Most of the measurements herewith presented have been obtained through local hydrographers, a comparatively small part of the work having been conducted directly from the office of the Geological Survey at Washington. Acknowledgment is therefore due to each of these persons individually. Thanks should also be extended to individuals and corporations who have cooperated in various ways, either by furnishing readings of height of water or assisting in transportation. The following list gives the names of the resident hydrographers or persons cooperating, this being arranged alphabetically by States:

Arizona: W. A. Farish, civil engineer, Phœnix; Albert T. Colton, civil engineer, Florence.

California: J. B. Lippincott, civil engineer, Los Angeles.

Colorado: A. L. Fellows, deputy State engineer, Denver.

Georgia and Alabama: Prof. B. M. Hall, civil engineer, Atlanta, Ga., and Prof. W. S. Yeates, State geologist, Atlanta.

Idaho: Frank S. Shirley, civil engineer, Boise.

Kansas: W. G. Russell, Russell; Prof. E. C. Murphy, State University, Lawrence.

Maryland: Prof. W. B. Clark, State geologist, Baltimore.

Montana: S. M. Emery, director experiment station, Bozeman; and Roe Emery, Bozeman.

Nebraska: Prof. O. V. P. Stout, State University, Lincoln, assisted by Adna Dobson and Glenn E. Smith.

Nevada: L. H. Taylor, civil engineer, Golconda.

New Mexico: P. E. Harroun, civil engineer, Santa Fe.

North and South Carolina: Prof. J. A. Holmes, State geologist, Chapel Hill, N. C., assisted by E. W. Myers.

Texas: Prof. Thomas U. Taylor, State University, Austin.

Utah: Prof. Samuel Fortier, civil engineer, Corinne.

Virginia and West Virginia: Prof. D. C. Humphreys, Washington and Lee University, Lexington, Va.

Washington: Sydney Arnold, civil engineer, North Yakima; William J. Ware, civil engineer, Port Angeles.

Wyoming: Clarence T. Johnston, civil engineer, Cheyenne.

In a number of instances related data have been inserted, such, for example, as results of computation of daily flow at mill dams, made by local engineers, and data of river heights obtained from the United States Weather Bureau or Corps of Engineers, United States Army. Reference to these facts, mainly unpublished, has been, or will be, made in other publications of this survey, and they are, therefore, placed in consecutive order for convenience of reference.

The methods of measurement of discharge of the various streams and the computations have been described in a general way on pages 18–30 of the Nineteenth Annual Report, Part IV. There has been gradual progress and development of details, but the operations there described have remained essentially unchanged.

NORTHERN ATLANTIC COAST DRAINAGE.

DESCRIPTION OF RIVER STATIONS.

aterville station on Kennebec River.—Computations of discharge of Kennebec River at Waterville, Maine, have been made by Mr. Sumner Hollingsworth, president of the Hollingsworth & Whitney Company, those beginning on November 15, 1891, being fragmentary in character through 1892. Prior to June 20, 1893, computations are based upon the flow over the dam as determined by weir formula. Subsequent to that date figures are from computations of the flow through turbines, using assumed readings, to which has been added any excess passing over the crest of the dam. The figures really give the discharge at noon on each day, this hour being the time when the flow is least affected by storage of dams upstream, and as giving most readily the average for the day. A summary of results is given on page 75 of the Nineteenth Annual Report, Part IV.

Rumford Falls station on Androscoggin River.—Computations of discharge made of Androscoggin River at Rumford Falls are described on page 92 of the Nineteenth Annual Report, Part IV. They begin on May 18, 1892, and extend to the end of April, 1895. Until January, 1893, the discharge was determined from the computed flow over the dam, as given by Francis's ordinary weir formula. Subsequent to that time, as water was used for power, additions were made to the computed flow over the dam of the amounts assumed to pass through the turbines, until July, 1895. Since that date the quantities are the sums of the actual measured quantities passing through the wheels and the computed flow over the dam. The gage readings are taken at the lower dam, and at first were made once a day, later four times a day, and subsequently every two hours. The results have been kindly furnished by Mr. Charles A. Mixer, resident engineer of the Rumford Falls Power Company. A summary of the results is given on page 93 of the Nineteenth Annual Report, Part IV.

Lambertville station on Delaware River.—Described on page 7 of Paper No. 15; results for 1897 shown on page 122 of the Nineteenth Annual Report, Part IV.

Harrisburg station on Susquehanna River.—Described on page 8 of Paper No. 15; results for 1897 given on page 122 of the Nineteenth Annual Report, Part IV.

Rowlandsville station on Octoraro Creek.—Described on page 12 of Paper No. 15; results for 1897 given on page 128 of the Nineteenth Annual Report, Part IV.

Woodstock station on Patapsco River.—Described on page 13 of Paper No. 15; results for 1897 given on page 129 of the Nineteenth Annual Report, Part IV.

Laurel station on Patuxent River.—Described on page 14 of Paper No. 15; results for 1897 shown on page 131 of the Nineteenth Annual Report, Part IV.

Sharpsburg station on Antietam Creek.—Described on page 16 of Paper No. 15; results for 1897 shown on page 149 of the Nineteenth Annual Report, Part IV. On January 26, 1898, a United States Geological Survey standard copper bolt bench mark was set in a rock on the left bank of the stream, 150 feet upstream from the point where the cable enters the ground. This is 16.34 feet above gage datum.

Port Republic station on North and South rivers.—Described on page 17 of Paper No. 15; result for 1897 shown on page 138 of the Nineteenth Annual Report. Part IV. No measurements were made on these rivers in 1898.

Millville station on Shenandoah River.—Described on page 19 of Paper No. 15; results for 1897 shown on pages 150 and 151 of the Nineteenth Annual Report, Part IV.

Frederick station on Monocacy River.—Described on page 20 of Paper No. 15; results for 1897 shown on page 154 of the Nineteenth Annual Report, Part IV.

Point of Rocks station on Potomac River.—Described on page 21 of Paper No. 15; results for 1897 shown on page 152 of the Nineteenth Annual Report, Part IV.

Park station on Rock Creek.—Described on page 22 of Paper No. 15; results for 1897 given on page 155 of the Nineteenth Annual Report, Part IV. No rating table was constructed for lack of sufficient data.

Glasgow station on North of James River.—Described on page 23 of Paper No. 15; results for 1897 given on page 162 of the Nineteenth Annual Report, Part IV.

Buchanan station on James River.—Described on page 24 of Paper No. 15; results for 1897 given on page 172 of the Nineteenth Annual Report, Part IV. The observer is W. H. Hyde. The temporary bench mark is the upper end of the fifth floor beam from the left bank. It is at an elevation of 30 feet above the zero of the gage.

TABLES OF DAILY DISCHARGE AND GAGE HEIGHT.

Daily discharge of Kennebec River at Waterville, Maine, in cubic feet per second, average for the twenty-four hours.

[Drainage area, 4,410 square miles.]

1892.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	.....	.....	.....	3,530	.....	11,840	17,355	.....	.....	.....	.....	.....
2	.....	.....	.....	4,730	7,920	.....	20,080	.....	.....	.....	.....	.....
3	.....	.....	.....	10,280	.....	11,840	.....	.....	.....	.....	.....	.....
4	.....	.....	.....	19,100	6,310	.....	29,985	.....	.....	.....	.....	.....
5	.....	.....	.....	25,250	.....	.....	.....	.....	.....	.....	.....	.....
6	.....	.....	.....	22,990	8,950	11,515	.....	.....	.....	.....	.....	.....
7	.....	.....	.....	28,150	.....	.....	.....	.....	.....	.....	.....	.....
8	.....	.....	.....	24,830	.....	8,200	.....	.....	.....	.....	.....	.....
9	.....	.....	.....	22,810	9,660	.....	.....	.....	.....	.....	.....	.....
10	.....	.....	.....	.....	.....	7,925	.....	.....	.....	.....	.....	.....
11	.....	.....	.....	18,090	5,900	.....	.....	.....	.....	.....	.....	.....
12	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
13	.....	.....	.....	11,195	7,650	7,375	.....	.....	.....	.....	.....	.....
14	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	a545	.....
15	.....	.....	.....	8,660	.....	7,100	.....	.....	.....	.....	a395	.....
16	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	a670	.....
17	.....	.....	.....	.....	6,940	8,490	.....	.....	.....	.....	a639	.....
18	.....	.....	.....	6,940	6,580	.....	.....	.....	.....	.....	a568	.....
19	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	a981	.....
20	.....	.....	.....	6,465	5,310	10,280	.....	.....	.....	.....	a1,449	.....
21	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	a1,488	.....
22	.....	.....	2,470	7,590	.....	17,355	.....	.....	.....	.....	a1,112	.....
23	.....	.....	.....	9,895	7,215	.....	.....	.....	.....	.....	.....	.....
24	.....	.....	2,430	.....	.....	19,640	.....	.....	.....	.....	a958	.....
25	.....	.....	2,250	.....	18,750	21,615	.....	.....	.....	.....	a1,399	.....
26	.....	.....	2,220	.....	.....	.....	.....	.....	.....	.....	a2,296	.....
27	.....	.....	2,000	13,160	10,750	19,250	.....	.....	.....	.....	.....	.....
28	.....	.....	2,325	.....	.....	19,640	.....	.....	.....	.....	.....	.....
29	.....	.....	2,990	8,780	.....	29,990	.....	.....	.....	.....	.....	.....
30	.....	.....	2,730	.....	12,160	20,080	.....	.....	.....	.....	.....	.....
31	.....	.....	3,080	.....	.....	.....	.....	.....	.....	.....	.....	.....

a These figures are for the year 1891. The closing of gates at Moosehead Lake is said to have caused the small discharge here recorded.

1893.

1	.....	2,350	2,500	4,100	21,700	13,200	10,840	1,940	2,490	.....	1,980	2,780
2	.....	2,250	2,500	4,250	21,200	16,250	.....	2,330	2,140	1,980	1,980	2,580
3	.....	2,200	2,450	4,500	27,600	15,200	9,990	2,380	.....	1,980	1,980	.....
4	.....	2,100	2,400	4,400	24,700	.....	11,230	2,360	1,890	1,710	1,980	.....
5	.....	2,100	2,400	3,700	60,500	13,800	8,840	2,290	1,890	1,980	.....	1,440
6	.....	2,200	2,400	3,700	46,500	15,250	9,740	.....	1,890	1,980	1,980	1,440
7	.....	2,300	2,350	3,600	36,700	16,250	8,410	2,240	2,260	1,980	2,250	1,440
8	.....	2,250	2,350	3,600	30,200	18,200	8,410	2,210	2,360	.....	1,980	1,440
9	.....	2,100	2,325	6,400	26,300	23,500	.....	2,360	2,680	1,980	1,980	1,440
10	.....	3,000	2,300	9,200	25,200	15,900	8,260	2,360	.....	1,980	1,980	.....
11	.....	2,400	2,300	12,400	27,000	.....	8,710	2,290	2,160	1,710	1,980	1,440
12	2,000	2,550	2,300	15,000	31,700	16,250	6,510	2,290	2,380	1,440	.....	1,440
13	2,100	2,600	5,400	16,500	31,300	23,200	6,410	.....	2,190	1,780	1,980	1,440
14	2,300	2,550	8,000	16,500	54,500	20,500	6,040	2,240	2,410	1,980	1,980	1,440
15	2,500	2,500	11,300	18,200	43,100	18,200	5,540	2,290	2,340	4,000	1,980	1,440
16	2,600	2,400	7,400	16,500	34,100	15,200	.....	2,430	2,175	3,050	1,980	1,440
17	4,800	2,300	6,300	14,100	30,700	13,200	4,840	2,210	.....	2,550	1,980	.....
18	5,000	2,200	6,100	14,000	83,500	13,200	4,490	2,150	1,710	2,550	2,250	1,710
19	4,200	2,100	5,700	14,100	46,100	11,200	3,660	2,290	1,710	1,980	.....	1,710
20	3,200	2,200	5,600	16,300	34,500	11,000	3,270	.....	2,200	2,250	2,250	1,440
21	2,100	2,350	4,600	14,500	.....	12,000	3,590	2,240	1,710	1,980	2,520	1,440
22	1,900	2,450	3,900	12,300	24,300	14,480	3,490	2,205	1,710	.....	2,250	1,440
23	2,100	2,350	3,600	13,800	22,800	13,640	.....	2,180	1,710	1,980	2,550	1,440
24	2,200	2,200	3,600	15,800	21,200	11,840	3,170	2,153	.....	1,980	2,480	.....
25	2,300	2,400	4,000	14,500	19,800	.....	2,830	2,295	1,710	3,380	1,980	.....
26	2,200	2,400	4,400	14,000	17,000	14,270	2,440	2,390	1,710	2,450	.....	1,440
27	2,200	2,450	4,400	14,200	16,300	14,000	2,380	.....	1,980	1,980	1,980	1,590
28	2,300	2,500	4,300	14,600	15,200	15,100	2,360	2,340	1,980	3,630	2,080	1,440
29	2,300	.....	4,200	14,800	14,550	14,600	2,240	2,310	1,710	3,530	3,980	1,590
30	2,350	.....	4,100	19,800	13,600	13,500	.....	2,230	1,980	3,280	3,630	1,590
31	2,400	.....	4,000	.....	13,900	.....	2,440	2,430	.....	2,280	.....	.....
Mean	2,650	2,350	4,180	11,660	30,520	15,290	5,770	2,270	2,040	2,330	2,230	1,580

Daily discharge of Kennebec River, at Waterville, Maine, in cubic feet per second, average for the twenty-four hours—Continued.

1894.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	1,470	1,910	1,740	.....	15,650	11,190	.....	3,305	2,253	2,181	3,896	1,570
2	1,640	1,910	1,740	4,496	14,510	12,930	7,030	3,240	1,125	1,923	7,295	.....
3	1,640	1,740	1,740	4,496	14,090	.....	6,860	3,143	2,312	1,915	5,619	2,187
4	1,640	.....	.....	4,370	13,220	12,930	.....	3,218	1,871	1,930	10,512	2,194
5	1,640	1,910	2,010	4,370	13,220	10,400	10,020	.....	2,207	1,896	9,486	2,213
6	1,640	1,910	1,740	5,473	.....	9,070	8,570	3,087	1,824	1,655	7,381	1,869
7	.....	1,740	1,910	4,720	12,280	9,070	7,965	3,019	2,209	.....	5,606	2,193
8	1,640	1,740	2,370	.....	10,100	8,520	.....	3,019	2,185	1,897	4,651	2,128
9	1,470	1,740	3,040	5,278	8,550	6,910	7,055	3,285	1,140	1,913	3,937	1,245
10	1,640	1,740	4,643	5,655	7,226	.....	6,336	3,045	2,293	1,913	3,739	1,937
11	1,640	.....	.....	5,950	7,050	5,900	6,674	3,050	2,034	5,553	3,040	1,211
12	1,470	1,740	5,390	6,980	6,110	.....	6,674	.....	2,818	6,738	3,636	1,694
13	1,640	1,740	5,390	7,170	.....	6,280	6,674	3,250	2,280	5,017	3,476	1,819
14	.....	1,740	6,220	6,980	5,840	5,900	6,336	3,125	2,309	8,387	2,782	2,386
15	1,470	1,740	5,580	.....	6,820	6,010	.....	3,005	2,341	9,036	2,500	2,600
16	1,640	1,740	4,460	12,150	7,410	5,900	6,674	3,010	.....	3,829	2,661	2,275
17	1,640	1,740	4,855	13,310	9,935	.....	6,046	3,110	2,183	7,527	2,489	2,513
18	1,470	.....	.....	20,640	9,935	.....	5,765	3,060	2,136	6,418	2,152	2,466
19	1,640	1,740	4,140	21,760	10,915	5,520	5,100	.....	1,883	5,088	2,631	2,331
20	1,640	1,740	5,405	22,910	.....	9,565	5,550	3,230	1,885	4,253	1,984	2,326
21	.....	1,760	3,802	26,860	13,540	10,055	4,885	3,050	12,102	3,231	2,446	2,205
22	1,640	1,760	6,660	.....	8,250	5,490	.....	2,915	6,659	3,730	2,502	2,208
23	1,640	1,810	6,395	35,280	6,100	6,265	3,680	2,825	4,673	3,576	2,495	1,229
24	1,640	1,810	5,215	33,680	6,360	.....	3,565	3,070	4,143	3,315	2,487	1,912
25	1,910	.....	.....	29,130	6,580	3,930	3,670	2,555	2,646	2,549	2,786	.....
26	1,910	1,760	4,855	25,210	10,560	3,781	3,830	.....	2,571	2,605	2,484	.....
27	1,910	1,740	4,184	21,980	.....	3,710	3,830	2,855	2,509	2,854	2,461	1,831
28	.....	1,740	4,180	20,680	8,090	10,480	3,830	2,494	2,378	.....	2,515	1,770
29	1,640	.....	3,895	.....	7,480	8,985	.....	2,615	1,918	2,859	1,444	1,657
30	1,640	.....	3,620	17,450	7,960	8,070	3,415	2,294	467	2,458	1,645	904
31	1,640	.....	3,510	.....	10,000	.....	3,345	2,400	.....	2,452	.....	1,227
Mean	1,640	1,780	4,020	14,680	9,570	7,790	5,720	2,970	2,740	3,750	3,760	1,930

1895.

1	1,135	2,214	1,685	2,176	13,227	9,818	5,042	3,153	1,792	1,106	1,061	5,904
2	1,599	2,208	1,687	2,205	11,967	9,314	4,315	3,062	2,867	1,149	1,347	4,682
3	1,655	1,738	1,252	2,406	11,461	8,408	4,278	3,063	2,560	1,130	1,870	8,378
4	1,664	2,174	1,720	2,638	12,172	7,979	3,784	1,576	2,226	1,110	1,421	5,842
5	1,608	2,444	2,229	6,164	11,934	7,364	4,062	3,015	2,212	1,152	2,201	3,519
6	1,780	2,077	2,145	7,891	12,584	7,870	3,844	2,738	2,200	.....	1,946	2,723
7	1,678	1,854	1,956	9,286	12,764	7,425	4,429	2,610	2,155	1,128	1,708	3,273
8	1,947	1,718	1,951	9,326	10,917	7,623	4,499	2,816	1,438	1,104	1,657	2,301
9	1,894	1,622	1,949	24,407	12,074	6,166	4,089	2,580	2,250	1,126	1,426	3,393
10	1,896	1,397	1,368	54,192	7,848	6,418	4,072	2,382	2,502	1,356	5,125	3,089
11	1,889	1,983	1,683	27,999	9,630	5,852	3,998	1,529	2,256	1,109	9,595	3,105
12	1,864	1,946	1,920	20,858	7,920	6,454	3,934	2,690	2,209	1,121	8,351	2,598
13	1,273	1,943	1,932	19,304	11,362	4,854	3,731	2,435	1,996	.....	6,279	2,378
14	2,403	1,967	1,946	24,061	16,175	5,887	3,658	2,405	1,970	1,185	3,882	2,524
15	2,441	1,648	2,236	86,201	12,878	6,925	3,767	2,160	1,150	1,141	3,869	1,747
16	2,481	1,950	2,224	70,381	12,121	6,592	3,631	2,433	1,736	1,134	4,972	2,545
17	2,490	579	1,566	43,406	9,842	6,156	3,508	2,118	1,710	1,250	6,455	2,069
18	2,509	2,112	2,224	34,708	7,895	6,121	3,546	857	1,987	1,546	5,695	2,021
19	2,439	1,708	2,194	31,068	8,668	5,616	3,512	2,681	1,721	1,587	4,591	1,928
20	1,817	1,689	1,937	31,562	7,807	5,905	3,222	2,072	1,741	.....	4,169	2,180
21	2,439	1,361	1,965	31,368	5,863	5,641	3,257	2,357	1,707	1,353	10,949	2,536
22	2,304	1,656	1,946	29,572	5,449	4,497	2,617	2,240	1,050	1,422	11,179	3,321
23	2,332	1,606	1,977	28,511	5,515	5,075	3,151	2,199	1,139	1,428	6,694	11,086
24	2,290	.....	1,627	23,707	8,261	5,046	2,875	2,722	1,387	1,432	5,124	9,147
25	2,333	1,629	2,241	20,348	8,037	5,670	2,863	1,658	1,167	1,372	5,632	6,136
26	2,319	1,676	2,314	18,931	6,919	6,216	2,590	4,284	1,155	1,399	4,804	5,162
27	1,706	1,714	2,769	15,499	7,533	6,280	2,552	5,069	1,104	.....	9,383	5,792
28	2,433	1,927	2,600	15,929	8,119	5,708	2,096	4,890	1,145	1,115	15,900	26,673
29	2,198	.....	2,418	10,853	6,109	5,690	2,671	3,450	.....	1,355	11,623	16,148
30	2,439	.....	2,459	13,216	4,868	4,955	2,930	3,080	1,115	1,385	9,372	14,590
31	2,127	.....	1,898	.....	8,982	.....	2,678	3,102	.....	1,081	.....	19,713
Mean	2,040	1,800	2,000	23,930	9,580	6,430	3,520	2,690	1,780	1,250	5,610	6,080

Daily discharge of Kennebec River at Waterville, Maine, in cubic feet per second, average for the twenty-four hours—Continued.

1896.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	3,281	2,643	6,257	5,527	29,468	7,491	4,811	3,730	2,643	2,870	3,238	8,049
2	21,881	1,292	111,246	5,861	26,601	11,004	4,374	2,696	2,611	2,975	4,259	6,844
3	17,367	2,717	52,691	6,647	25,207	6,846	4,236	3,595	1,772	3,734	4,023	5,730
4	11,482	2,522	24,810	6,442	18,064	5,891	5,578	3,597	2,577	2,275	3,757	2,200
5	6,708	2,243	13,866	5,782	26,583	5,318	5,249	3,037	2,371	5,249	3,435	2,603
6	4,153	2,236	13,170	5,709	30,879	4,961	11,678	3,044	2,129	4,567	29,865	2,545
7	3,803	2,857	11,862	5,373	29,499	4,343	11,214	3,313	6,903	3,954	23,836	3,312
8	4,329	4,634	10,323	4,998	25,090	4,391	9,685	3,468	7,978	3,277	17,040	2,851
9	2,970	3,962	8,950	5,040	22,228	4,374	8,690	.....	6,094	3,210	15,322	2,870
10	2,971	3,452	9,499	5,199	19,997	5,953	7,149	4,113	4,624	3,166	12,152	2,852
11	3,006	3,140	5,469	6,757	20,249	3,855	6,047	4,737	4,003	2,394	10,028	2,851
12	2,755	3,002	5,226	8,356	21,463	6,252	4,637	4,276	3,668	2,626	11,389	2,938
13	2,970	2,816	6,109	16,221	19,072	5,235	4,844	3,906	1,857	2,617	11,777	2,385
14	2,689	2,967	3,651	11,472	18,994	5,142	4,437	3,695	2,952	2,363	10,962	2,981
15	2,595	2,879	.....	15,989	18,066	4,679	4,289	3,414	3,002	2,388	9,319	2,874
16	2,990	2,193	3,888	46,946	16,696	4,944	4,449	2,566	2,789	2,311	8,426	2,307
17	2,513	2,829	10,129	64,700	17,981	4,549	5,121	3,197	2,336	2,384	7,947	2,272
18	2,736	2,824	3,159	61,270	14,846	4,536	5,125	3,137	2,932	2,016	7,952	1,489
19	1,568	2,758	4,087	57,188	15,227	4,219	4,495	3,178	3,590	2,319	8,130	2,303
20	2,782	2,763	6,699	52,131	13,163	4,710	4,596	3,079	1,733	2,326	7,547	1,870
21	3,090	2,781	12,922	74,469	14,782	5,352	4,391	2,858	4,313	2,352	6,572	2,547
22	2,767	2,771	3,239	60,021	13,215	6,073	4,419	2,747	4,207	4,208	5,222	2,287
23	2,793	2,162	10,025	41,711	3,976	6,655	4,374	2,759	4,147	8,956	3,749	2,047
24	2,542	3,854	7,820	46,693	23,517	6,275	4,258	2,943	3,754	7,804	4,606	1,768
25	2,394	2,812	6,608	40,793	14,220	6,334	4,386	2,990	2,924	7,986	6,185	1,579
26	1,881	2,790	6,637	36,126	4,482	5,817	3,794	2,851	2,969	6,227	6,322	1,506
27	2,499	2,772	7,253	32,729	5,729	5,459	4,215	2,571	2,474	5,388	5,683	1,497
28	2,765	2,558	10,886	30,217	5,117	5,309	3,781	2,410	3,149	2,644	6,169	2,317
29	2,531	2,794	5,945	30,517	4,867	4,200	3,728	2,416	3,148	3,214	8,424	2,063
30	2,473	.....	6,901	30,977	3,192	5,307	3,335	1,625	2,777	2,888	8,432	1,845
31	2,220	.....	5,006	.....	6,092	.....	3,831	2,531	.....	2,891	.....	1,787
Mean	4,304	2,830	13,140	27,400	17,050	5,520	5,330	3,150	3,410	3,768	9,059	2,750

1897.

1	2,073	3,587	2,007	6,334	39,001	18,204	8,719	12,975	4,771	2,314	2,911	4,630
2	2,085	3,485	2,950	7,648	34,299	16,780	9,885	13,656	4,357	2,048	2,637	3,825
3	1,650	3,775	2,423	9,075	32,654	17,526	9,531	11,263	4,340	967	6,687	3,754
4	2,318	3,598	2,629	9,635	34,210	17,542	8,512	9,206	3,701	2,532	9,442	3,190
5	3,732	3,348	2,586	11,536	40,730	17,549	7,147	7,796	3,090	2,490	8,628	3,063
6	18,504	3,223	2,522	12,889	36,362	15,756	8,189	7,226	3,865	2,375	7,729	5,968
7	10,210	4,185	4,026	18,329	28,923	16,023	7,410	5,889	3,571	2,158	6,457	6,382
8	5,860	4,305	2,703	21,149	26,610	15,785	7,922	5,761	4,008	1,533	6,443	5,229
9	5,028	5,634	2,285	18,268	24,400	13,801	7,967	4,000	3,973	2,097	5,195	5,172
10	3,793	6,225	2,291	15,458	23,995	12,961	7,270	5,243	3,997	2,100	7,927	4,879
11	3,293	5,933	4,554	16,671	41,196	16,003	6,290	5,849	4,808	2,109	8,133	4,212
12	3,601	5,007	4,230	14,377	41,223	14,962	5,761	7,562	9,689	1,508	7,313	4,048
13	3,084	4,629	5,238	13,999	23,965	13,819	7,256	9,771	5,463	1,788	6,350	5,765
14	2,542	3,897	5,045	14,796	41,284	15,304	45,507	7,112	4,915	6,070	2,789	6,104
15	2,881	4,070	5,387	16,881	38,988	16,003	55,634	6,601	4,864	6,323	4,902	7,153
16	2,715	4,028	4,925	24,426	32,431	14,617	33,770	5,368	4,325	5,528	4,420	13,621
17	2,187	3,848	2,533	34,813	27,453	14,638	26,160	7,776	4,333	3,837	5,913	14,005
18	2,942	3,163	2,025	28,642	23,788	13,344	21,286	11,566	3,239	3,262	7,191	11,381
19	1,918	2,467	2,304	31,734	21,013	11,200	17,067	8,562	3,632	3,287	6,428	7,665
20	2,211	2,480	2,339	32,799	18,843	11,390	12,542	6,755	3,488	2,322	4,391	5,835
21	2,283	3,543	3,167	26,949	17,562	10,649	7,747	7,129	5,043	2,331	4,161	6,799
22	2,222	2,636	2,083	24,087	15,105	7,399	5,218	7,907	8,422	2,326	3,009	5,419
23	2,951	2,427	2,621	24,008	15,448	9,991	8,408	6,616	7,438	2,051	2,703	3,861
24	2,300	2,302	5,547	29,875	14,809	9,095	8,980	5,718	5,838	1,510	2,181	3,839
25	1,953	2,544	5,832	33,605	10,818	8,353	8,925	5,816	4,481	2,140	2,687	3,225
26	1,847	2,877	6,345	42,860	16,539	8,751	10,826	6,280	3,841	2,348	1,889	2,541
27	2,727	2,825	5,992	51,255	21,779	7,590	9,842	6,220	4,555	2,415	6,097	2,563
28	2,252	3,705	5,311	66,907	24,568	7,691	7,950	5,706	4,084	2,973	13,399	2,685
29	2,477	.....	4,994	58,745	26,000	8,023	6,734	5,382	2,915	2,008	6,883	3,001
30	4,024	.....	5,071	43,797	22,697	8,345	6,405	5,154	2,801	2,344	6,171	2,733
31	3,534	.....	5,513	.....	20,526	.....	11,707	4,364	.....	2,600	.....	2,699
Mean	3,587	3,705	3,790	25,385	26,943	12,970	13,115	7,298	4,595	2,635	5,702	5,330

Daily discharge of Kennebec River at Waterville, Maine, in cubic feet per second, average for the twenty-four hours—Continued.

1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	2,475	2,539	4,170	20,385	36,048	14,341	4,385	3,790	.....	.....	.....	.....
2	2,284	2,955	4,188	16,556	39,372	13,776	4,343	2,707	.....	.....	.....	.....
3	2,222	2,687	5,648	13,871	38,301	10,900	3,440	2,887	.....	.....	.....	.....
4	2,715	3,090	5,163	12,143	37,358	8,791	3,490	2,833	.....	.....	.....	.....
5	2,771	2,775	2,997	10,830	37,730	9,846	4,343	2,809	.....	.....	.....	.....
6	3,431	3,068	4,094	10,150	37,569	10,301	4,272	3,712	.....	.....	.....	.....
7	1,807	3,475	5,070	7,080	31,580	9,189	4,477	3,252	.....	.....	.....	.....
8	4,826	2,994	5,033	6,563	29,880	9,098	4,203	4,374	.....	.....	.....	.....
9	5,434	3,744	4,767	7,472	28,753	12,541	5,464	4,218	.....	.....	.....	.....
10	4,492	3,154	4,623	10,457	25,636	14,318	1,745	4,017	.....	.....	.....	.....
11	3,025	3,829	5,329	15,299	22,059	12,086	4,111	3,048	.....	.....	.....	.....
12	3,286	3,317	6,752	19,848	21,899	11,322	4,484	3,413	.....	.....	.....	.....
13	3,240	3,680	8,397	44,854	24,042	11,003	4,267	2,927	.....	.....	.....	.....
14	3,287	3,912	9,880	47,141	34,332	10,777	3,776	1,130	.....	.....	.....	.....
15	4,909	4,026	11,534	50,381	32,988	12,514	4,327	3,443	.....	.....	.....	.....
16	3,717	4,042	12,816	49,415	27,500	11,295	3,994	2,499	.....	.....	.....	.....
17	3,891	3,764	12,215	47,112	24,756	10,584	3,611	2,560	.....	.....	.....	.....
18	3,453	3,221	11,918	47,321	23,440	9,478	3,896	2,491	.....	.....	.....	.....
19	3,460	3,267	12,484	44,700	23,153	9,196	3,968	2,622	.....	.....	.....	.....
20	3,505	2,885	13,218	39,327	20,592	11,129	3,747	2,526	.....	.....	.....	.....
21	3,893	3,172	14,580	36,671	19,088	10,855	3,835	913	.....	.....	.....	.....
22	4,614	3,764	17,177	33,789	18,570	9,950	5,068	3,425	.....	.....	.....	.....
23	2,542	2,133	16,615	30,792	17,073	8,334	3,871	2,866	.....	.....	.....	.....
24	2,321	3,437	15,987	34,352	15,277	9,483	3,418	3,425	.....	.....	.....	.....
25	2,866	4,352	17,812	52,119	15,993	8,864	3,747	2,849	.....	.....	.....	.....
26	2,032	3,933	17,029	45,520	15,589	7,508	3,879	4,432	.....	.....	.....	.....
27	3,136	3,653	16,560	38,083	15,639	5,267	3,385	4,218	.....	.....	.....	.....
28	2,905	4,387	18,928	37,354	14,611	4,326	4,189	3,940	.....	.....	.....	.....
29	2,727	.....	19,762	33,652	16,632	5,689	3,444	3,396	.....	.....	.....	.....
30	1,738	.....	17,711	31,767	16,962	6,715	3,204	3,555	.....	.....	.....	.....
31	2,607	.....	27,432	.....	16,298	.....	2,832	2,857	.....	.....	.....	.....
Mean	3,213	3,402	11,287	29,833	25,120	9,983	3,908	3,133	.....	.....	.....	.....

Daily discharge of Androscoggin River at Rumford Falls, Maine, in cubic feet per second, average for the twenty-four hours.

[Drainage area, 2,320 square miles.]

1892.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	.....	.....	.....	.....	.....	6,500	16,300	3,200	5,860	2,700	2,580	3,830
2	.....	.....	.....	.....	.....	7,000	11,800	3,450	5,860	.....	2,820	3,580
3	.....	.....	.....	.....	.....	5,540	.....	3,450	5,240	2,700	3,060	2,820
4	.....	.....	.....	.....	.....	6,500	16,700	3,450	.....	2,700	4,080	.....
5	.....	.....	.....	.....	.....	6,150	17,500	3,450	4,940	2,940	3,830	3,050
6	.....	.....	.....	.....	.....	6,150	14,800	3,450	4,940	2,940	.....	3,580
7	.....	.....	.....	.....	.....	6,150	12,600	.....	4,350	2,940	2,820	3,580
8	.....	.....	.....	.....	.....	5,540	12,000	3,320	4,080	2,700	3,060	3,830
9	.....	.....	.....	.....	.....	5,540	11,000	2,820	3,580	.....	5,860	3,830
10	.....	.....	.....	.....	.....	4,360	.....	2,820	3,580	2,700	4,650	3,200
11	.....	.....	.....	.....	.....	4,080	10,000	2,600	.....	2,700	3,320	.....
12	.....	.....	.....	.....	.....	4,350	9,300	4,080	3,200	2,700	2,820	3,200
13	.....	.....	.....	.....	.....	3,830	6,500	4,350	3,200	2,700	.....	3,200
14	.....	.....	.....	.....	.....	3,830	6,500	.....	3,200	2,700	2,330	3,200
15	.....	.....	.....	.....	.....	3,830	5,240	5,870	8,000	2,700	2,580	3,200
16	.....	.....	.....	.....	.....	4,080	4,940	5,870	4,940	.....	4,650	2,940
17	.....	.....	.....	.....	.....	3,830	.....	4,940	4,080	2,700	24,500	2,940
18	.....	.....	.....	.....	5,860	4,080	4,650	4,940	.....	2,700	13,000	.....
19	.....	.....	.....	.....	5,550	3,830	3,830	4,350	3,300	2,700	16,300	2,940
20	.....	.....	.....	.....	4,940	4,080	4,080	4,650	3,050	2,700	.....	2,940
21	.....	.....	.....	.....	4,940	11,000	3,700	.....	2,580	2,700	8,300	2,940
22	.....	.....	.....	.....	5,540	11,200	3,700	5,540	3,060	2,700	7,500	2,940
23	.....	.....	.....	.....	7,500	7,500	3,700	4,650	3,830	.....	5,550	2,940
24	.....	.....	.....	.....	11,700	6,500	.....	4,650	3,330	2,940	4,950	2,940
25	.....	.....	.....	.....	9,300	7,000	3,950	4,350	.....	2,940	4,080	.....
26	.....	.....	.....	.....	8,600	13,000	3,950	8,500	3,080	2,940	4,350	.....
27	.....	.....	.....	.....	8,900	11,300	3,580	8,500	3,830	2,940	.....	2,940
28	.....	.....	.....	.....	9,300	15,800	3,320	.....	3,580	2,940	4,350	2,940
29	.....	.....	.....	.....	8,600	19,900	2,820	8,500	3,060	2,940	3,830	3,200
30	.....	.....	.....	.....	8,000	19,900	4,660	8,500	3,060	.....	3,580	3,200
31	.....	.....	.....	.....	8,500	.....	.....	6,500	.....	2,700	.....	3,200
Mean	.....	.....	.....	.....	7,640	7,410	7,330	4,840	4,030	2,780	5,720	3,200

Daily discharge of Androscoggin River at Rumford Falls, Maine, in cubic feet per second, average for the twenty-four hours—Continued.

1893.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	.....	2,990	2,990	2,870	9,560	5,040	3,310	2,840	3,760	.....	3,570	3,820
2	3,580	2,990	2,750	.....	11,460	5,040	.....	2,840	3,260	2,900	3,570	2,860
3	3,580	2,990	2,750	3,250	11,460	4,450	3,310	3,080	.....	2,450	3,340	.....
4	3,830	2,990	2,750	3,250	11,760	.....	3,580	2,840	2,560	2,450	3,340	1,900
5	3,200	.....	.....	2,750	25,460	4,750	3,630	2,580	2,360	2,890	.....	2,260
6	2,940	2,990	2,750	2,750	17,060	4,750	3,580	2,840	2,560	2,660	3,080	2,260
7	2,940	2,990	2,990	2,750	.....	5,040	3,580	3,820	2,760	2,260	3,080	2,860
8	.....	2,990	2,990	2,750	14,260	6,250	3,310	3,820	3,270	.....	3,340	2,460
9	2,940	2,990	2,990	.....	14,260	4,750	.....	2,840	3,530	2,750	3,340	2,460
10	2,940	2,990	2,990	5,910	17,060	5,040	3,310	2,840	.....	2,660	2,870	.....
11	3,200	2,990	2,990	4,700	24,060	.....	3,580	2,580	2,560	2,860	2,670	2,260
12	3,200	.....	.....	5,910	27,860	9,700	2,590	2,580	2,560	2,660	.....	2,060
13	3,200	2,990	3,250	7,050	27,860	8,400	2,590	2,840	3,040	2,660	2,670	2,260
14	3,200	2,990	4,130	7,050	.....	7,100	2,120	2,370	2,350	4,340	2,460	2,260
15	.....	2,990	4,130	8,050	28,460	7,100	2,310	1,960	2,160	.....	2,670	2,460
16	3,200	2,990	3,880	.....	25,060	6,600	.....	1,800	2,570	6,840	2,770	2,460
17	3,200	2,990	3,250	5,000	30,460	5,650	2,310	1,900	.....	3,580	2,770	.....
18	3,200	2,990	3,250	4,700	38,060	.....	2,120	1,750	3,280	4,320	2,770	2,460
19	3,200	.....	.....	4,700	26,060	4,450	2,590	2,580	3,280	3,670	.....	2,460
20	3,200	2,990	3,250	4,400	21,060	5,950	2,590	2,870	2,560	3,080	2,860	2,460
21	3,200	2,990	3,250	5,000	.....	5,100	2,820	3,560	2,560	3,080	2,860	2,460
22	.....	2,990	3,250	5,280	16,760	5,350	2,590	3,060	2,360	.....	3,340	2,260
23	3,200	2,990	3,250	.....	14,260	5,350	.....	3,060	2,160	3,340	3,080	2,260
24	3,200	2,990	2,990	5,590	13,060	5,740	2,590	3,060	.....	4,330	2,680	.....
25	3,200	2,990	2,990	5,910	9,660	.....	2,810	4,080	2,300	13,000	2,060	3,820
26	3,200	.....	.....	5,590	8,860	8,400	3,070	4,850	2,360	6,450	.....	2,860
27	3,200	2,990	3,370	6,550	6,560	6,250	2,590	4,080	3,040	4,320	1,900	3,340
28	2,940	2,990	3,380	7,050	.....	5,640	2,590	3,320	2,150	4,060	2,460	3,080
29	.....	.....	3,110	7,050	5,610	3,080	2,820	3,080	2,350	.....	4,830	3,080
30	2,940	.....	3,370	.....	5,610	3,160	2,330	12,300	2,350	4,830	4,320	3,080
31	2,940	.....	3,060	.....	5,110	.....	2,820	4,850	.....	3,820	.....	.....
Mean	3,180	2,990	3,190	5,030	17,630	5,640	2,800	3,290	2,660	3,830	3,070	2,660

1894.

1	3,570	2,130	1,680	.....	13,730	9,430	.....	1,680	1,980	1,680	7,380	1,880
2	3,570	2,130	1,570	4,290	13,730	9,830	3,110	1,750	.....	1,570	5,060	1,980
3	2,290	1,980	1,570	4,050	14,230	.....	2,280	1,980	1,830	1,730	4,560	1,980
4	2,290	.....	.....	4,050	11,730	9,830	5,310	2,130	1,980	1,980	.....	2,030
5	2,490	2,130	1,980	3,570	10,530	6,730	3,810	.....	1,980	1,680	5,060	2,030
6	2,700	2,130	2,130	3,900	9,730	5,880	3,090	1,380	1,930	1,460	4,050	2,180
7	.....	1,980	3,310	3,570	8,530	5,580	2,280	1,680	1,830	.....	3,300	2,280
8	2,490	2,130	5,880	.....	8,530	5,310	.....	2,030	1,680	1,680	2,890	1,570
9	2,490	2,280	5,310	3,570	7,730	4,810	2,480	2,280	.....	1,780	3,100	.....
10	2,280	2,130	5,310	3,300	7,380	.....	2,700	2,480	3,800	5,580	2,930	1,980
11	2,280	.....	.....	3,570	7,080	4,810	2,480	2,130	2,890	4,050	.....	1,830
12	2,280	2,280	4,550	3,570	5,880	3,100	3,310	.....	1,980	2,890	3,300	2,480
13	2,130	1,680	5,310	3,570	.....	4,060	2,280	1,830	1,630	3,800	2,890	2,890
14	.....	1,980	3,800	3,570	5,070	4,060	2,130	1,980	1,630	.....	2,280	2,730
15	2,280	1,680	4,560	4,300	4,550	3,800	.....	2,130	1,680	3,100	2,730	2,530
16	2,280	2,310	3,800	5,880	4,550	3,800	2,480	2,130	.....	2,690	2,530	.....
17	2,130	1,680	3,570	7,730	5,070	.....	2,280	2,130	1,680	2,890	2,730	2,280
18	2,130	.....	.....	9,030	4,810	4,550	2,480	2,280	1,830	2,890	.....	2,030
19	2,130	1,980	3,570	12,530	4,570	6,170	1,980	.....	2,180	2,530	3,100	2,130
20	3,310	1,980	5,570	17,730	.....	5,310	1,830	2,130	5,880	2,480	1,830	2,730
21	.....	1,980	7,090	22,230	6,170	5,310	3,300	1,980	3,310	.....	1,930	2,330
22	3,310	1,830	5,570	.....	6,170	4,550	.....	1,880	2,480	2,280	2,700	1,460
23	3,310	1,680	5,310	20,630	5,880	3,800	1,980	1,680	.....	2,280	2,700	.....
24	3,570	1,680	4,300	19,230	5,880	.....	1,830	1,680	2,280	2,280	2,890	1,880
25	3,570	.....	.....	18,730	6,470	3,100	1,830	1,730	2,130	2,330	.....	2,030
26	3,310	1,680	4,300	16,530	11,630	3,100	2,130	.....	1,830	2,690	2,490	1,980
27	3,310	1,680	4,050	15,230	.....	3,100	2,130	1,680	1,880	2,130	1,680	1,480
28	.....	1,570	3,800	16,930	5,880	4,050	2,280	1,680	1,830	.....	2,130	1,880
29	2,890	.....	3,570	.....	5,070	4,600	.....	1,880	1,680	2,180	1,460	1,980
30	2,890	.....	3,800	14,930	19,230	4,050	1,830	1,830	.....	2,280	1,380	.....
31	2,280	.....	3,570	.....	10,830	.....	1,680	2,030	.....	.....	.....	1,830
Mean	2,720	2,000	4,030	9,470	8,240	5,090	2,490	1,930	2,220	2,500	3,040	2,090

Daily discharge of Androscoggin River at Rumford Falls, Maine, in cubic feet per second, average for the twenty-four hours—Continued.

1895.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	2,130	1,460	1,230	1,330	10,780	5,030	2,010	1,870	.....	6,380	1,730	4,970
2	2,180	1,380	1,230	1,230	9,060	.....	2,000	1,980	1,400	3,700	2,160	4,870
3	2,130	.....	.....	1,230	7,780	4,430	1,950	2,000	1,450	2,570	2,310	5,980
4	2,130	1,330	1,230	1,330	9,060	4,350	2,300	.....	1,860	2,570	1,860	2,870
5	2,530	1,230	1,230	1,230	.....	4,010	2,090	1,900	1,710	2,690	1,860	2,850
6	.....	1,230	1,230	1,230	9,350	3,760	1,890	1,860	1,700	.....	1,860	2,810
7	2,130	1,230	1,230	2,130	8,330	3,400	.....	1,660	1,840	2,360	2,020	2,830
8	2,030	1,230	1,230	3,100	7,570	3,230	2,020	1,640	.....	2,200	2,530	2,880
9	1,980	1,230	1,230	15,030	7,770	.....	2,000	1,600	1,550	2,200	2,290	2,400
10	1,830	.....	.....	9,730	7,880	3,100	1,960	1,760	1,710	2,200	6,440	2,190
11	1,680	1,230	1,230	6,790	6,390	2,700	2,010	.....	1,620	2,180	5,190	2,250
12	1,570	1,230	1,230	5,570	.....	2,170	1,920	2,080	2,070	2,020	2,970	2,440
13	.....	1,230	1,230	8,730	17,070	2,060	1,890	2,000	2,130	.....	2,470	1,890
14	1,630	1,230	1,230	.....	11,570	2,380	.....	1,860	1,600	5,130	2,300	1,890
15	2,490	1,230	1,230	55,230	8,730	2,580	1,880	1,770	.....	3,980	2,230	2,070
16	2,130	1,230	1,230	38,230	7,770	.....	1,840	1,730	1,780	2,770	3,540	1,990
17	1,630	1,230	1,230	17,630	7,480	3,000	1,740	1,720	1,620	2,550	3,010	2,260
18	1,630	1,230	1,230	13,530	6,700	2,360	1,760	.....	1,530	2,350	2,520	2,220
19	2,480	1,230	1,230	12,030	.....	2,240	1,760	1,990	1,580	2,200	2,800	2,350
20	.....	1,230	1,230	12,930	6,290	2,180	1,690	1,900	1,580	.....	2,600	2,280
21	1,460	1,230	1,230	.....	5,630	2,180	.....	1,760	1,630	2,110	3,970	2,270
22	1,480	1,230	1,230	16,530	5,330	2,150	1,490	1,580	.....	1,950	3,060	3,470
23	1,480	1,230	1,230	16,530	5,030	.....	1,350	1,590	1,970	1,880	2,340	9,420
24	1,580	.....	.....	16,530	4,230	2,320	1,350	1,700	2,130	1,830	2,780	5,860
25	1,380	1,230	1,230	14,930	4,230	2,330	1,400	.....	2,240	1,880	2,770	4,500
26	1,380	1,230	1,230	14,930	.....	2,320	1,350	2,000	2,370	1,880	2,640	3,250
27	.....	1,230	1,230	13,730	3,600	2,330	1,350	1,880	2,960	.....	15,650	8,460
28	1,460	1,230	1,230	.....	8,730	2,500	.....	1,770	2,910	1,890	7,870	12,420
29	1,330	.....	1,230	12,930	7,730	2,710	1,750	1,860	.....	1,740	5,760	6,970
30	1,450	.....	1,230	10,730	6,530	.....	1,600	1,890	4,790	1,690	5,470	4,030
31	1,380	.....	.....	.....	5,330	.....	1,580	1,770	.....	1,640	.....	12,640
Mean	1,800	1,250	1,230	12,000	7,628	2,873	1,775	1,819	1,989	2,539	3,566	4,180

Daily gage height, in feet, of Delaware River at Lambertville, New Jersey, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1	4.30	(a)	5.45	6.30	5.70	5.70	3.60	3.95	5.15	3.35	5.05	5.40
2	4.05	(a)	5.20	5.85	5.45	5.30	3.50	4.20	4.70	3.25	4.90	5.20
3	3.90	(a)	5.05	5.55	5.20	5.05	3.40	5.40	4.50	2.95	4.70	5.05
4	(a)	(a)	5.10	5.35	5.20	4.90	3.30	4.70	4.35	2.90	4.60	5.00
5	(a)	(a)	4.80	5.10	5.25	4.75	3.20	5.35	4.25	2.90	4.45	6.85
6	(a)	(a)	4.70	4.95	5.35	4.60	3.20	6.40	4.25	2.90	4.40	6.30
7	(a)	(a)	4.65	4.85	5.60	4.40	3.05	6.20	4.25	2.90	4.35	6.10
8	(a)	4.40	4.50	4.75	7.10	4.40	3.00	5.25	4.25	3.95	4.30	5.75
9	4.30	4.50	4.60	4.70	7.95	4.30	3.00	4.80	4.55	4.05	4.30	5.45
10	4.25	4.45	4.80	4.60	6.80	4.20	2.90	4.85	4.60	3.90	4.80	5.45
11	4.25	4.55	5.25	4.50	6.10	4.10	2.90	6.20	4.35	4.35	5.55	5.00
12	4.20	4.80	5.90	4.40	5.80	4.15	2.65	5.35	4.15	4.10	7.60	5.15
13	4.25	5.25	7.30	4.40	5.95	4.00	2.70	4.90	4.05	3.85	7.15	4.80
14	4.55	6.85	8.30	4.30	5.65	4.00	2.60	4.55	3.95	3.90	6.30	4.95
15	5.45	6.20	8.00	4.45	6.25	4.55	2.50	4.45	3.80	4.10	5.75	(a)
16	5.85	5.55	6.80	4.80	6.00	4.30	2.50	4.30	3.75	4.60	5.45	(a)
17	5.50	5.30	6.10	4.45	6.60	4.15	2.40	4.10	3.70	5.50	5.30	(a)
18	5.20	4.85	5.85	4.30	6.50	4.00	2.50	4.35	3.65	5.00	5.15	(a)
19	4.75	4.60	5.55	4.25	6.05	3.90	2.60	4.50	3.55	4.70	6.85	4.50
20	4.80	7.95	5.50	4.20	6.05	3.90	4.20	4.45	3.45	4.60	6.85	4.85
21	5.85	8.85	6.60	4.20	6.60	3.90	3.70	4.75	3.30	4.50	7.15	4.80
22	6.50	9.60	6.60	4.05	6.55	4.10	3.70	5.00	3.30	4.60	6.65	4.70
23	8.00	8.85	6.60	4.10	6.00	4.05	3.30	4.55	3.40	4.65	6.50	5.85
24	8.40	7.85	8.30	4.35	7.00	3.95	3.10	4.35	3.50	4.80	6.30	5.95
25	7.70	7.00	7.95	5.80	6.15	3.70	3.00	6.95	3.45	4.70	6.10	6.30
26	7.05	6.55	6.95	7.35	6.95	3.70	3.20	7.25	3.30	4.70	5.90	5.95
27	6.40	6.05	6.40	7.30	7.65	3.60	3.40	6.45	3.25	5.20	5.90	5.50
28	5.85	5.75	6.10	6.80	7.35	3.55	3.40	5.50	3.20	5.90	5.35	5.25
29	5.60	.....	6.10	6.50	7.00	3.50	4.20	5.10	3.20	5.95	5.35	4.70
30	5.05	.....	6.45	6.10	6.60	3.65	4.20	4.80	3.30	5.45	5.40	4.95
31	4.90	.....	6.75	.....	6.10	.....	4.05	4.60	.....	5.25	.....	4.90

a Frozen.

Daily gage height, in feet, of Susquehanna River at Harrisburg, Pennsylvania, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	2.66	3.91	4.66	8.66	6.00	4.33	2.00	1.41	2.66	0.75	4.66	3.08
2	2.33	3.41	4.33	7.41	5.41	4.16	2.16	1.50	2.33	.75	4.00	3.16
3	2.16	3.00	4.16	6.41	4.83	3.91	2.00	1.41	3.00	.66	3.66	3.08
4	2.66	2.66	3.91	5.75	4.66	3.58	1.75	2.33	2.50	.66	3.50	3.00
5	1.91	2.66	3.66	5.41	4.41	3.33	1.66	4.58	2.08	.66	3.16	3.66
6	1.91	2.66	3.58	4.91	4.43	3.00	1.58	5.33	1.91	.66	3.90	5.00
7	2.25	2.66	3.50	4.50	4.66	2.83	1.50	4.00	1.66	.66	2.91	4.50
8	2.50	3.08	3.50	4.41	5.50	2.66	1.41	3.50	1.66	1.00	2.50	4.08
9	2.66	3.41	3.33	4.16	6.25	2.50	1.33	3.08	1.66	1.33	2.50	3.83
10	2.75	3.50	3.33	3.83	5.58	2.50	1.25	3.66	2.00	1.41	2.50	3.58
11	3.00	3.41	3.83	3.66	5.16	2.33	1.16	4.25	2.83	2.25	2.58	3.08
12	3.00	3.75	4.91	3.50	4.75	2.33	1.08	3.75	2.75	2.40	4.00	2.50
13	3.33	4.41	6.50	3.33	4.50	2.25	1.00	3.33	2.58	2.33	3.75	2.25
14	4.00	7.66	8.66	3.25	4.00	2.25	.91	2.66	2.08	2.00	3.00	2.25
15	6.95	8.16	9.83	3.16	4.00	2.41	.83	2.50	1.91	2.00	6.58	2.08
16	8.08	7.50	9.33	3.66	4.25	2.75	.83	2.25	1.75	2.08	5.50	2.00
17	7.83	6.50	8.08	4.08	5.16	3.25	.75	2.00	1.41	2.16	4.83	2.00
18	7.58	5.83	7.16	3.91	6.08	3.00	.66	1.91	1.33	3.25	4.33	1.91
19	6.58	5.00	6.33	3.66	5.33	2.66	.66	2.33	1.16	3.75	4.16	2.00
20	5.83	4.33	5.83	3.50	5.50	2.41	.75	3.00	1.00	4.00	4.16	2.50
21	5.75	4.66	7.33	3.41	6.66	2.33	.91	4.41	.91	4.33	4.25	2.91
22	6.16	6.83	9.25	3.33	6.66	2.33	.75	4.33	.91	4.25	4.58	3.08
23	7.41	6.91	10.91	3.16	6.50	2.08	.91	3.75	.91	7.33	4.83	3.50
24	9.25	7.75	15.63	3.00	6.00	2.00	.83	3.41	.83	8.33	4.66	5.41
25	10.50	6.66	15.25	3.50	7.00	2.16	.83	3.00	.83	7.41	4.33	7.83
26	9.50	6.25	11.66	6.66	6.50	2.08	.83	2.66	.75	6.16	4.00	7.66
27	8.00	5.66	9.25	10.33	6.50	2.00	1.33	2.50	.91	5.66	3.91	6.33
28	7.00	5.00	7.75	9.50	6.16	1.91	1.16	2.41	.91	5.58	3.66	5.33
29	6.08	.....	6.66	8.16	5.75	1.83	1.83	4.16	.75	5.66	3.50	4.89
30	5.50	.....	7.00	6.66	5.33	1.66	1.58	3.83	.75	6.08	3.33	4.33
31	4.83	.....	9.00	.....	4.91	.....	1.33	3.00	.....	5.33	.....	3.83

Daily gage height, in feet, of Octoraro Creek at Rowlandsville, Maryland, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	3.40	3.70	3.60	4.10	3.90	3.90	3.40	3.30	3.30	3.40	3.40	4.60
2	3.60	3.70	3.60	4.00	3.80	3.80	3.30	3.30	3.30	3.40	3.75	4.60
3	3.60	3.70	3.60	3.90	3.80	3.80	3.30	3.40	3.30	3.40	4.55	4.50
4	3.50	3.75	3.60	3.80	3.70	3.70	3.80	5.85	3.30	3.40	4.55	4.75
5	3.45	3.70	3.50	3.80	3.75	3.70	3.70	4.90	3.30	3.40	4.55	9.25
6	3.40	3.70	3.50	3.80	3.80	3.70	3.50	4.35	3.30	3.40	4.90	8.40
7	3.40	3.60	3.50	3.70	4.25	3.70	3.40	3.95	3.45	3.30	4.50	6.70
8	3.40	3.65	3.50	3.70	4.30	3.60	3.40	3.85	3.90	3.30	4.05	5.90
9	3.40	3.65	3.50	3.70	4.05	3.60	3.40	4.00	3.50	3.30	3.90	5.30
10	3.40	3.65	3.50	3.60	3.80	3.60	3.30	4.50	3.50	3.30	3.75	4.90
11	3.40	3.60	3.50	3.60	3.85	3.50	3.30	3.45	3.50	3.40	3.60	3.65
12	3.55	3.50	3.50	3.60	4.25	3.50	3.30	3.80	3.40	3.40	3.50	3.60
13	4.30	3.50	3.50	3.60	4.10	3.50	3.30	3.70	3.40	3.40	3.85	3.60
14	3.60	3.50	3.50	3.50	4.10	3.50	3.30	3.55	3.40	3.40	3.65	3.60
15	4.40	3.50	3.50	3.50	4.25	3.50	3.30	3.50	3.30	3.40	3.60	3.50
16	4.60	3.50	3.50	3.50	5.00	3.50	3.30	3.60	3.30	3.30	3.60	3.50
17	3.85	3.40	3.50	3.50	5.25	3.50	3.30	3.70	3.30	3.30	4.70	3.50
18	3.45	3.45	3.50	3.50	4.95	3.50	3.30	4.50	3.30	3.30	4.90	3.50
19	3.40	3.90	3.50	3.50	4.55	3.50	3.55	4.25	3.30	3.30	6.20	3.90
20	3.75	5.10	3.50	3.50	4.85	4.35	3.55	3.80	3.20	3.30	5.70	9.05
21	3.85	4.60	3.50	3.50	4.90	3.75	3.35	3.50	3.20	3.95	5.15	7.80
22	3.50	3.95	3.60	3.50	4.50	3.70	3.30	3.50	3.20	3.65	4.95	6.05
23	4.30	3.80	3.80	4.30	4.25	3.70	3.30	3.50	4.10	3.50	4.65	6.75
24	3.80	3.80	4.10	4.10	4.20	3.60	3.30	3.50	3.80	3.40	4.70	4.35
25	3.65	3.70	5.10	3.90	4.35	3.60	3.30	6.35	3.60	3.40	4.85	4.30
26	4.00	3.70	3.80	4.05	4.10	3.60	3.30	3.35	3.40	3.40	4.10	4.20
27	3.70	3.60	3.70	4.15	4.80	3.50	3.30	3.70	4.20	3.35	4.90	4.10
28	3.55	3.60	3.70	4.00	4.05	3.50	3.95	3.60	3.90	3.60	4.75	4.00
29	3.50	.....	3.75	4.00	4.00	3.45	3.85	3.45	3.55	3.55	4.80	4.00
30	3.50	.....	4.65	3.90	3.90	3.40	3.45	3.30	3.45	3.50	4.70	3.90
31	3.60	.....	4.30	.....	3.90	.....	3.70	3.30	.....	3.40	.....	4.15

Daily gage height, in feet, of Patapsco River at Woodstock, Maryland, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	3.95	3.95	4.00	4.15	4.05	3.80	3.50	6.05	3.40	3.35	4.00	3.90
2	3.95	4.10	4.00	4.15	4.05	3.80	3.40	4.65	3.35	3.20	3.55	3.90
3	3.95	4.10	4.00	4.15	3.90	3.80	3.40	3.70	3.25	3.40	3.60	4.30
4	3.90	4.05	4.10	4.05	4.00	3.85	3.40	3.60	3.35	3.45	3.55	4.70
5	3.85	4.00	4.10	4.05	4.00	3.80	3.50	3.85	3.25	3.45	3.55	5.95
6	3.90	4.00	4.00	4.05	4.40	3.80	3.50	3.80	3.20	3.45	3.55	4.80
7	3.85	4.10	4.05	4.10	4.80	3.80	3.55	3.75	3.25	3.45	3.55	4.15
8	3.80	3.90	4.05	4.00	4.95	3.75	3.50	3.70	3.20	3.35	3.40	4.15
9	3.85	4.05	3.90	3.50	4.65	3.75	3.55	3.70	3.20	3.35	3.40	4.05
10	3.55	3.95	3.95	3.50	4.30	5.75	3.50	5.65	3.35	3.25	3.60	4.05
11	4.20	3.95	3.95	3.95	4.20	.....	3.60	4.20	3.10	3.25	4.35	4.00
12	4.25	4.00	4.00	4.10	4.35	3.75	3.45	3.85	3.45	3.45	3.35	3.95
13	4.20	3.50	4.05	4.00	4.30	4.25	3.45	4.10	3.35	3.35	3.35	3.95
14	4.05	3.50	4.05	3.90	4.10	3.90	3.45	3.95	3.30	3.40	3.40	3.95
15	5.00	3.90	4.00	4.30	4.25	3.80	3.35	3.75	3.30	3.45	3.35	(a)
16	4.65	3.65	3.95	4.10	5.10	3.70	3.45	3.60	3.40	3.35	3.65	.....
17	4.25	3.90	4.00	3.90	4.85	3.70	3.15	3.60	3.35	3.50	4.15	.....
18	4.00	3.95	3.85	3.90	4.30	3.70	3.35	3.70	3.05	3.35	4.15	.....
19	3.95	4.55	3.85	3.90	4.20	3.60	3.60	4.00	3.20	4.25	5.15	.....
20	4.25	4.65	3.85	4.00	4.20	3.60	3.60	3.75	3.30	3.75	4.20	.....
21	4.20	5.20	4.00	3.90	4.20	3.65	3.55	3.70	3.30	3.80	3.70	.....
22	4.05	4.45	4.00	3.90	4.20	3.65	3.75	3.65	3.30	4.10	3.85	.....
23	4.65	4.20	4.00	3.90	4.25	3.60	3.60	3.60	3.60	3.80	3.95	.....
24	4.30	4.10	4.15	4.50	4.20	3.60	3.40	3.40	3.60	3.65	3.85	.....
25	4.10	4.10	4.40	4.20	4.10	3.55	3.55	3.40	3.35	3.50	3.75	.....
26	4.65	4.00	4.00	4.10	4.05	3.40	3.60	3.60	3.40	3.50	3.80	.....
27	4.25	4.00	4.00	4.00	4.00	3.50	3.60	3.60	3.35	3.50	3.75	.....
28	4.10	3.95	4.00	4.10	4.00	3.50	4.10	3.55	3.35	3.50	3.75	.....
29	4.10	.....	4.15	4.10	3.80	3.45	3.70	3.50	3.35	3.50	3.75	.....
30	4.05	.....	4.80	4.00	3.85	3.50	3.55	3.45	3.35	4.30	3.85	.....
31	4.05	.....	4.50	.....	3.90	.....	3.50	3.60	.....	4.20	.....	.....

a Bridge floor taken up; gage removed December 16 to 31.

Daily gage height, in feet, of Patuxent River at Laurel, Maryland, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.
1	5.10	4.90	4.65	5.00	4.40	4.40	3.80	5.15
2	4.80	4.85	4.55	4.85	4.45	4.35	3.90	4.50
3	4.90	5.30	4.70	4.60	4.35	4.35	3.20	3.80
4	4.95	5.00	5.05	4.70	4.45	4.35	3.20	3.95
5	4.85	5.00	4.70	4.80	4.50	3.90	3.95	10.15
6	4.60	5.10	4.45	4.60	4.70	4.40	3.65	4.55
7	4.65	5.15	4.55	4.60	5.85	4.35	3.80	4.05
8	4.70	5.40	4.55	4.60	5.70	4.25	3.60	4.00
9	4.75	4.90	4.60	4.45	5.60	4.35	3.55	4.80
10	6.30	4.75	4.55	4.40	4.95	4.35	3.55	6.50
11	5.85	4.75	4.55	4.60	7.25	4.25	3.50	(a)
12	4.95	4.60	4.55	4.50	7.10	4.15	2.95	.....
13	5.00	4.65	4.40	4.55	5.95	4.20	3.05	.....
14	5.00	4.65	4.55	4.45	5.00	6.00	2.85	.....
15	6.60	4.65	4.50	4.75	4.50	4.40	3.00	.....
16	6.30	4.65	4.60	4.70	4.60	4.30	3.70	.....
17	5.55	4.50	4.70	4.35	8.40	4.25	3.50	.....
18	5.35	4.50	4.55	4.45	6.45	4.30	3.60	.....
19	5.05	5.35	4.45	4.50	4.85	4.40	3.60	.....
20	5.15	5.80	4.25	4.50	4.80	4.20	3.70	.....
21	5.50	6.45	4.50	4.45	4.70	4.10	3.75	.....
22	5.25	5.75	4.45	4.50	4.55	4.10	3.75	.....
23	5.90	5.00	4.35	4.30	4.80	3.95	3.40	.....
24	5.10	4.90	4.55	4.40	4.70	3.95	3.15	.....
25	5.10	4.85	5.70	4.80	4.50	3.85	3.55	.....
26	5.50	4.75	4.50	4.45	4.50	3.95	3.05	.....
27	5.50	4.65	4.35	4.35	4.50	3.90	5.85	.....
28	5.10	4.85	4.55	4.45	4.45	4.15	5.70	.....
29	4.85	.....	4.65	4.65	4.10	4.10	3.95	.....
30	4.90	.....	6.65	4.55	4.55	3.90	3.05	.....
31	4.85	.....	5.55	.....	4.45	.....	3.35	.....

a Gage torn out; bridge being repair. Station discontinued.

Daily gage height, in feet, of Antietam Creek at Sharpsburg, Maryland, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	2.00	2.40	2.10	2.80	2.00	2.40	1.80	2.00	1.90	1.80	2.10	2.80
2	2.40	2.60	2.10	2.70	2.00	2.30	1.70	1.90	1.90	1.80	2.10	2.20
3	2.10	2.90	2.10	2.60	2.00	2.20	1.80	1.80	1.90	1.70	2.00	2.00
4	1.80	3.50	2.10	2.50	2.00	2.20	1.80	1.90	1.90	1.70	2.10	2.60
5	1.70	2.40	2.20	2.60	2.00	2.10	1.80	2.50	2.10	1.70	1.90	7.80
6	1.50	2.20	2.10	2.50	2.10	2.20	1.80	2.00	2.00	1.60	1.80	3.85
7	1.90	2.40	2.10	2.50	2.20	2.20	1.70	1.80	1.90	1.70	1.80	3.25
8	1.80	2.20	2.10	2.50	2.40	2.10	1.70	1.80	1.90	1.60	1.70	3.00
9	1.70	2.10	2.00	2.40	3.25	2.10	1.80	2.00	1.90	1.60	1.70	2.90
10	2.00	2.10	2.00	2.40	2.70	2.10	1.80	3.10	1.80	1.60	1.90	2.80
11	2.10	2.30	2.10	2.40	2.50	2.10	1.80	3.05	1.70	1.60	2.50	2.70
12	1.90	2.20	2.10	2.30	2.40	2.15	1.80	2.30	1.90	1.80	2.15	2.70
13	2.00	2.20	2.00	2.30	2.50	2.20	1.80	2.10	1.80	1.70	2.20	2.70
14	1.80	2.20	2.00	2.30	2.30	2.20	1.80	2.00	1.80	1.80	2.20	2.80
15	2.90	2.20	2.10	2.35	2.30	2.10	1.80	2.05	1.90	1.70	2.00	2.70
16	3.15	2.10	2.00	2.40	2.90	2.10	1.70	2.00	1.80	1.50	2.00	2.80
17	2.90	2.00	2.20	2.30	3.00	2.10	1.70	2.00	1.80	1.60	1.90	2.50
18	2.50	2.20	2.20	2.30	2.80	2.10	1.80	5.05	1.70	2.75	2.00	2.40
19	2.30	2.30	2.20	2.30	2.60	2.00	1.80	3.65	1.90	1.80	2.60	2.50
20	2.40	2.10	2.00	2.30	2.40	2.10	1.80	2.95	1.80	2.40	2.50	3.15
21	2.40	2.60	2.10	2.20	2.40	2.00	1.80	2.45	1.80	2.20	2.40	2.90
22	2.20	2.60	2.50	2.20	3.10	1.90	1.80	2.30	1.80	2.90	2.40	2.80
23	2.85	2.40	2.55	2.20	2.50	2.10	1.80	2.10	1.90	2.80	2.30	3.85
24	2.80	2.60	2.70	2.20	3.00	2.10	1.80	2.00	1.90	1.90	2.40	3.20
25	2.60	2.30	3.25	2.30	2.70	1.90	2.20	1.90	1.80	1.70	2.30	3.00
26	2.60	2.30	2.95	2.30	2.90	1.90	1.90	2.00	1.80	2.40	2.30	2.90
27	2.60	2.20	2.80	2.20	2.70	1.90	1.90	2.00	1.90	2.30	2.30	2.80
28	2.50	2.30	2.70	2.20	2.70	1.80	1.80	1.90	1.80	2.10	2.30	2.60
29	2.50	.....	2.75	2.20	2.60	1.80	1.80	2.00	1.90	2.10	2.20	2.60
30	2.40	.....	3.10	2.10	2.50	1.80	1.80	2.00	1.80	2.10	2.20	2.50
31	2.50	.....	2.90	.....	2.40	.....	1.90	2.00	.....	2.10	.....	2.60

Daily gage height, in feet, of North River at Port Republic, Virginia, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	2.15	2.70	2.10	3.85	2.65	2.35	2.20	4.25	2.60	2.40	3.00	2.40
2	2.15	2.70	2.10	3.50	2.60	2.30	2.20	4.25	2.50	2.40	2.80	2.30
3	2.15	2.70	2.10	3.30	2.50	2.15	2.20	4.00	2.50	2.40	2.65	2.30
4	2.10	2.70	2.10	3.15	2.45	2.15	2.20	4.50	2.50	2.40	2.60	3.00
5	2.10	2.70	2.10	3.00	2.40	2.15	2.20	3.00	2.50	3.00	2.60	7.00
6	2.10	2.65	2.10	2.90	3.00	2.10	2.20	5.00	2.50	2.90	2.60	5.00
7	2.05	2.65	2.10	2.90	6.40	2.10	2.20	5.00	2.50	2.80	2.50	3.60
8	2.05	2.60	2.10	2.80	7.25	2.10	2.20	4.60	2.50	2.60	2.50	3.30
9	2.00	2.50	2.10	2.60	6.30	2.10	2.20	4.00	2.50	2.40	2.45	3.00
10	2.60	2.40	2.10	2.75	5.00	2.00	2.15	9.00	2.50	2.25	2.40	2.90
11	2.55	2.30	2.10	2.75	4.00	2.00	2.10	9.00	2.50	2.10	2.40	2.80
12	2.50	2.20	2.10	2.75	3.60	2.60	2.10	7.00	2.50	2.10	2.40	2.70
13	2.45	2.20	2.10	2.75	3.80	2.50	2.00	6.00	2.50	2.10	2.35	2.65
14	2.45	2.15	2.10	2.75	3.20	2.35	2.00	6.00	2.50	2.00	2.35	2.60
15	2.45	2.15	2.10	4.15	3.00	2.20	2.10	6.00	2.50	2.00	2.30	2.55
16	2.45	2.10	2.10	5.20	2.80	4.20	2.10	4.50	2.50	2.00	2.30	2.50
17	2.45	2.10	2.25	4.50	2.80	3.40	2.25	4.20	2.50	2.00	2.25	2.50
18	2.45	2.10	2.80	4.00	2.70	3.00	2.50	4.00	2.50	2.00	2.20	2.40
19	2.55	2.10	2.95	3.50	2.60	3.00	2.40	4.00	2.50	9.50	2.15	2.30
20	2.55	2.10	2.85	3.20	2.60	3.00	2.30	3.60	2.50	5.00	2.60	2.30
21	2.55	2.10	2.75	3.00	2.60	3.00	2.30	3.30	2.50	5.00	2.60	2.30
22	2.55	2.10	2.75	2.90	3.35	2.90	2.30	3.20	2.50	10.00	2.60	2.30
23	2.70	2.10	2.75	2.75	3.30	2.80	2.30	3.10	2.75	6.50	2.60	4.00
24	2.80	2.10	2.75	2.75	3.20	2.65	3.00	3.10	2.75	5.00	2.60	4.30
25	2.80	2.10	2.85	2.75	3.00	2.50	2.80	3.00	2.65	3.80	2.60	3.60
26	2.80	2.10	2.90	2.75	2.90	2.50	2.70	2.90	2.65	3.65	2.60	3.30
27	2.80	2.10	3.00	2.75	2.75	2.50	3.50	2.80	2.60	3.50	2.55	3.00
28	2.70	2.10	3.00	2.70	2.65	2.40	4.75	2.70	2.60	3.30	2.50	2.80
29	2.70	.....	3.00	2.65	2.65	2.40	5.00	2.70	2.50	3.15	2.50	2.60
30	2.70	.....	3.30	2.65	2.50	2.40	5.00	2.60	2.40	3.15	2.50	2.60
31	2.70	.....	4.20	.....	2.40	.....	4.50	2.60	2.40	3.15	.....	2.60

Daily gage height, in feet, of South River at Port Republic, Virginia, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	1.80	2.00	1.50	2.25	2.10	1.75	1.60	2.10	1.60	1.35	2.50	1.90
2	1.80	2.00	1.50	2.25	2.05	1.65	1.60	2.00	1.50	1.35	2.35	1.80
3	1.80	2.00	1.60	2.25	2.00	1.60	1.55	2.00	1.50	1.35	2.20	1.80
4	1.75	2.00	1.60	2.20	2.00	1.60	1.55	2.00	1.50	1.35	2.15	2.50
5	1.75	2.00	1.60	2.15	1.90	1.60	1.55	4.40	1.50	1.75	2.10	4.00
6	1.65	1.95	1.60	2.15	2.20	1.60	1.55	3.00	1.50	3.00	2.10	3.00
7	1.65	1.90	1.60	2.15	4.10	1.60	1.55	2.40	1.50	2.90	2.05	2.90
8	1.60	1.85	1.60	2.10	5.00	1.60	1.55	2.40	1.50	2.60	2.00	2.70
9	1.60	1.80	1.60	2.00	4.10	1.55	1.55	2.30	1.50	2.30	2.00	2.50
10	1.60	1.75	1.60	2.10	3.50	1.55	1.50	6.40	1.50	2.15	2.00	2.40
11	1.60	1.70	1.60	2.05	3.10	1.50	1.45	6.60	1.50	2.00	2.00	2.35
12	1.55	1.70	1.60	2.00	2.90	1.85	1.40	3.60	1.50	1.95	2.00	2.30
13	1.55	1.65	1.60	2.00	2.60	1.75	1.40	3.00	1.50	1.90	2.00	2.30
14	1.55	1.60	1.60	2.00	2.60	1.65	1.40	3.00	1.50	1.80	1.90	2.25
15	1.55	1.55	1.60	2.75	2.50	1.55	1.60	2.80	1.50	1.80	1.90	2.20
16	1.55	1.50	1.60	3.00	2.40	1.75	1.60	2.60	1.50	1.80	1.90	2.15
17	1.55	1.50	1.85	2.80	2.40	1.75	1.60	2.40	1.50	1.75	1.90	2.10
18	1.55	1.50	1.85	2.70	2.30	1.75	1.60	2.30	1.50	1.75	1.85	2.10
19	1.55	1.50	1.85	2.50	2.20	1.75	1.60	2.30	1.50	7.50	1.85	2.10
20	1.55	1.50	1.80	2.40	2.10	1.75	1.60	2.20	1.50	3.80	2.15	2.00
21	1.55	1.50	1.80	2.25	2.00	1.75	1.60	2.20	1.50	3.80	2.10	2.00
22	1.55	1.50	1.80	2.15	2.60	1.75	1.60	2.20	1.50	7.60	2.10	2.00
23	2.00	1.50	1.80	2.10	2.00	1.70	1.60	2.20	1.65	4.50	2.10	2.60
24	2.00	1.50	1.90	2.10	2.00	1.70	1.70	2.10	1.65	4.00	2.10	2.60
25	2.00	1.50	1.90	2.20	1.90	1.70	1.70	2.00	1.60	3.10	2.10	2.50
26	2.00	1.50	1.90	2.50	1.90	1.70	1.70	1.90	1.50	3.00	2.10	2.45
27	2.00	1.50	2.00	2.30	1.85	1.65	1.70	1.80	1.45	2.80	2.10	2.40
28	2.00	1.50	2.00	2.25	1.80	1.60	1.70	1.70	1.40	2.60	2.10	2.35
29	2.00	.....	2.00	2.20	1.80	1.60	1.70	1.60	1.35	2.50	2.10	2.30
30	2.00	.....	2.00	2.10	1.80	1.60	1.70	1.60	1.35	2.50	2.00	2.30
31	2.00	.....	2.20	.....	1.80	.....	2.10	1.60	.....	2.50	.....	2.30

Daily gage height, in feet, of Shenandoah River at Millville, West Virginia, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	1.10	1.60	0.60	3.50	1.80	1.40	0.70	1.70	1.50	0.90	2.80	2.10
2	.80	1.60	.60	3.40	1.70	1.30	.....	.90	1.50	.90	2.40	2.10
3	.70	1.30	.60	2.70	1.50	1.20	.70	.70	1.70	1.00	2.50	2.10
4	.90	1.20	.60	2.50	1.40	1.10	.70	1.00	1.50	1.00	2.70	2.50
5	.50	1.60	.50	2.30	1.20	1.10	.60	3.20	1.40	1.20	2.10	5.40
6	.70	1.10	.60	2.10	1.20	1.10	.60	7.90	1.40	1.80	2.00	6.00
7	.50	1.40	.60	2.00	1.60	1.00	.50	3.70	1.40	1.50	2.00	4.60
8	.90	1.40	.60	1.90	5.90	.90	.50	1.50	1.40	1.10	1.90	3.80
9	.50	1.20	.60	1.80	8.50	.80	.50	3.50	1.30	1.50	1.90	3.00
10	.70	.90	.50	1.60	7.00	.70	.50	6.20	1.30	1.40	1.80	2.80
11	1.20	.90	.50	1.40	5.00	.70	.60	11.70	1.10	1.30	1.90	2.60
12	.80	.90	.50	1.30	4.00	.70	.70	9.00	1.10	1.20	1.80	2.40
13	1.60	.70	.50	1.30	3.30	.60	.70	5.60	1.10	1.00	1.70	2.40
14	1.50	.70	.50	1.30	2.90	1.00	.70	4.70	1.10	1.00	1.80	2.20
15	1.60	.70	.50	1.80	2.50	1.00	.70	3.70	1.00	1.00	1.70	1.90
16	3.20	.60	.50	4.10	2.40	1.00	.70	3.50	1.00	1.00	1.70	2.20
17	2.50	.50	.70	5.20	2.30	.90	.70	3.60	1.00	1.10	1.70	2.20
18	2.20	.50	1.90	4.00	2.00	1.00	.70	3.40	1.10	1.10	1.70	2.20
19	1.70	.60	1.60	3.40	1.80	1.50	.60	2.80	1.00	7.75	1.80	2.30
20	1.70	.60	1.70	3.00	1.70	1.40	.50	3.40	1.00	8.40	2.30	2.00
21	1.70	.60	1.70	2.40	1.60	1.10	.70	2.70	1.00	5.00	2.70	2.00
22	1.60	.90	1.60	2.20	1.60	1.30	.70	2.40	1.00	5.00	2.50	2.00
23	1.60	.90	1.50	2.00	2.00	1.00	.60	2.30	1.10	9.10	2.50	2.30
24	1.70	.90	1.50	1.80	2.50	1.00	.50	2.10	1.10	5.70	2.50	2.90
25	1.70	.80	2.50	1.70	3.00	1.10	1.20	2.00	1.10	4.40	2.30	4.00
26	1.80	.80	2.70	1.70	2.50	.80	1.10	2.00	1.40	3.50	2.30	3.50
27	2.20	.70	2.50	1.70	2.00	.70	1.10	1.60	1.20	3.40	2.20	3.00
28	2.00	.70	2.20	1.90	2.00	.70	1.00	1.80	1.10	2.20	2.00	2.80
29	1.80	.....	2.20	1.80	2.00	.70	1.00	1.60	1.10	3.00	2.00	2.50
30	1.10	.....	2.50	1.80	1.70	.70	1.20	1.60	1.00	2.90	2.20	2.40
31	1.40	.....	3.00	.....	1.50	.....	1.70	1.60	.....	2.90	.....	2.30

Daily gage height, in feet, of Monocacy River at Frederick, Maryland, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	5.25	5.40	5.40	7.10	4.70	5.50	4.40	4.70	4.00	3.80	5.50	6.30
2	5.20	6.50	5.30	6.90	4.70	5.40	4.30	4.60	4.00	3.80	5.30	6.20
3	6.00	6.50	5.30	6.00	4.60	5.30	4.30	4.40	4.00	3.80	4.70	5.50
4	5.70	6.50	5.70	5.80	4.60	5.20	4.30	4.10	4.00	3.80	4.60	7.00
5	5.50	6.10	6.20	5.80	4.60	5.10	4.40	7.65	3.90	3.80	4.50	17.95
6	5.50	6.10	6.00	5.80	4.60	5.10	4.40	6.90	3.90	3.80	4.40	8.50
7	5.50	5.50	5.90	5.80	6.20	5.10	4.40	5.10	3.90	3.80	4.40	7.00
8	5.60	5.00	5.50	5.50	7.00	5.00	4.40	4.20	4.00	3.90	4.40	6.40
9	5.70	5.20	5.30	5.50	13.40	5.00	4.40	4.10	4.00	3.90	4.40	5.70
10	6.50	5.40	5.20	5.20	7.50	5.00	4.40	6.70	4.00	3.80	4.70	5.50
11	7.10	5.40	5.20	5.20	6.50	5.00	4.30	12.40	3.90	3.80	9.70	5.30
12	7.20	6.00	5.10	5.20	6.50	5.00	4.20	6.00	3.80	3.90	6.90	5.30
13	8.10	6.20	5.10	5.10	8.20	5.00	4.20	5.40	3.80	3.80	5.40	5.30
14	8.50	5.60	5.10	5.10	6.00	4.90	4.20	5.40	3.80	3.80	5.30	5.30
15	11.90	5.50	5.00	5.30	5.60	4.90	4.20	4.60	3.80	4.00	5.20	5.20
16	11.40	5.30	5.00	5.90	6.75	4.90	4.10	4.50	3.80	4.20	5.00	5.00
17	8.75	5.20	5.00	5.50	11.55	4.70	4.10	4.50	3.80	3.90	5.50	5.00
18	7.50	5.10	5.00	5.00	7.50	4.60	4.10	6.35	3.80	5.50	6.10	5.00
19	6.90	6.40	5.00	4.90	6.50	4.50	4.10	10.10	3.80	6.25	12.35	6.00
20	6.90	6.50	4.90	4.90	6.50	4.50	4.30	7.00	3.80	5.60	9.50	9.60
21	9.00	14.80	6.10	4.90	6.40	4.50	5.40	5.50	3.80	4.90	6.85	8.60
22	9.50	12.00	7.30	4.80	6.00	4.50	4.40	4.90	3.90	11.55	5.90	8.80
23	12.75	7.50	7.60	4.80	6.00	4.50	4.10	4.60	4.15	9.00	5.90	13.60
24	9.50	6.50	7.60	5.00	6.60	4.40	4.00	4.50	4.20	7.10	6.30	8.00
25	7.50	6.30	10.75	5.30	6.70	4.40	3.90	4.40	4.10	5.20	5.90	7.50
26	8.70	5.70	8.50	5.30	6.60	4.40	3.90	4.30	3.90	5.20	5.40	6.10
27	8.00	5.60	6.60	5.00	6.30	4.40	4.30	4.30	3.90	5.50	5.20	6.00
28	7.30	5.40	6.60	4.90	5.90	4.40	4.30	4.20	3.90	5.30	5.20	5.90
29	6.50	.....	7.70	4.90	5.80	4.40	4.30	4.10	3.90	5.10	5.30	5.50
30	5.90	.....	9.50	4.80	5.70	4.40	4.20	4.10	3.80	5.10	5.70	5.50
31	5.70	.....	7.90	.....	5.60	.....	4.00	4.00	.....	6.00	.....	5.50

Daily gage height, in feet, of Potomac River at Point of Rocks, Maryland, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	2.90	2.80	1.90	6.10	2.60	2.20	0.90	1.50	1.20	0.70	2.70	2.10
2	2.90	1.70	1.80	5.20	2.40	2.00	.80	1.70	1.10	.70	2.50	2.10
3	3.00	2.00	1.70	4.60	2.20	1.80	.80	1.40	1.10	.60	2.30	2.00
4	3.20	1.90	1.70	4.10	2.00	1.70	.70	1.20	1.00	.70	2.20	2.50
5	3.20	1.90	1.60	3.80	1.90	1.60	.70	2.20	1.00	.80	2.00	5.10
6	3.30	2.00	1.60	3.60	1.80	1.40	.70	7.20	1.00	.80	1.80	9.20
7	3.20	2.00	1.60	3.20	2.20	1.30	.70	6.10	1.10	1.00	1.80	6.10
8	2.90	1.90	1.50	2.90	5.40	1.30	.80	3.70	1.00	1.10	1.70	4.50
9	3.00	1.90	1.50	2.40	11.05	1.20	.70	3.90	1.00	1.00	1.60	3.60
10	3.20	1.80	1.40	2.50	9.60	1.20	.70	5.60	.90	1.00	1.60	3.00
11	3.90	1.80	1.40	2.50	6.50	1.10	.70	14.00	.90	.90	2.00	2.60
12	5.80	1.90	1.50	2.40	5.20	1.10	.60	16.05	.90	.90	1.80	2.40
13	5.70	2.00	1.50	2.40	4.20	1.10	.50	9.50	.80	1.40	1.80	2.20
14	5.30	1.90	1.60	2.50	3.70	1.30	.50	8.00	.80	1.20	2.00	2.20
15	5.50	1.90	1.60	2.50	3.10	1.30	.50	7.20	.80	1.00	2.00	2.00
16	6.70	2.00	1.70	4.00	3.00	1.30	.50	6.10	.80	.80	1.80	1.80
17	8.00	2.00	1.70	9.00	3.20	1.30	.50	5.20	.80	.80	1.80	1.80
18	6.70	1.80	2.00	6.70	4.60	1.20	.50	4.30	.80	.80	1.80	2.00
19	5.60	1.70	5.80	5.10	4.40	1.50	.70	3.30	.80	1.40	2.20	2.10
20	4.90	1.70	4.60	4.20	3.50	1.40	.70	3.10	.70	9.00	3.00	2.20
21	4.70	2.80	3.50	3.50	2.30	1.30	.90	3.00	.70	5.40	3.60	2.60
22	4.60	3.80	3.50	3.20	2.90	1.30	.90	3.80	.70	5.35	3.30	3.30
23	5.00	4.10	6.60	2.90	3.10	1.30	1.10	2.80	.70	13.10	3.20	4.70
24	9.40	3.40	6.20	2.60	3.90	1.20	.90	2.30	.70	10.10	3.10	6.20
25	8.40	2.90	6.40	2.60	5.10	1.10	.80	2.00	.70	5.90	3.00	6.90
26	5.10	2.60	10.50	2.60	5.60	1.10	.90	1.80	.70	4.50	2.70	5.30
27	5.00	2.30	7.20	2.50	4.10	1.00	1.20	1.50	.90	3.80	2.60	4.30
28	5.10	2.10	5.30	3.30	3.40	1.00	1.00	1.50	.80	3.60	2.40	3.70
29	5.10	.....	4.40	3.00	3.00	.90	1.20	1.40	.70	3.40	2.20	3.20
30	3.60	.....	4.30	2.80	2.80	.90	1.40	1.30	.70	3.00	2.10	3.00
31	3.40	.....	6.20	.....	2.40	.....	1.70	1.30	.....	2.80	.....	2.70

Daily gage height, in feet, of Rock Creek at Park station, District of Columbia, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	3.10	3.15	3.10	3.30	3.50	2.95	2.85	2.80	2.45	2.30	2.80	2.95
2	2.95	3.15	3.10	3.20	3.50	2.95	2.80	2.80	2.40	2.35	2.65	2.80
3	3.10	3.10	3.10	3.20	3.50	2.95	2.80	2.80	2.40	2.35	2.60	2.80
4	3.05	3.10	3.15	3.10	3.00	2.90	2.80	2.80	2.40	2.40	2.60	3.15
5	3.05	3.05	3.15	3.20	3.50	2.90	2.85	3.90	2.40	2.40	2.60	4.45
6	3.00	3.05	3.10	3.15	3.20	2.90	2.85	2.85	2.40	2.40	2.65	3.15
7	3.05	3.05	3.10	3.10	3.95	2.90	2.80	2.80	2.40	2.40	2.65	3.00
8	3.05	3.05	3.10	3.10	3.40	2.90	2.80	2.80	2.35	2.35	2.60	2.90
9	3.05	3.10	3.05	3.10	3.30	2.90	2.80	2.90	2.35	2.35	2.60	2.85
10	3.90	3.10	3.05	3.10	3.00	2.90	2.80	3.45	2.35	2.35	2.65	2.85
11	3.35	3.10	3.05	3.05	3.00	2.90	2.80	3.70	2.35	2.35	3.40	2.75
12	3.20	3.10	3.05	3.15	3.15	2.90	2.75	4.00	2.30	2.40	3.85	2.80
13	3.30	3.10	3.05	3.15	3.15	2.90	2.75	4.15	2.30	2.40	2.70	2.85
14	3.20	3.05	3.05	3.15	3.15	3.20	2.75	3.95	2.30	2.45	2.65	2.80
15	3.40	3.05	3.05	3.15	3.10	2.90	2.80	2.75	2.30	2.40	2.65	2.80
16	4.10	3.05	3.05	3.10	3.10	2.85	2.80	2.80	2.30	2.45	2.65	2.80
17	3.30	3.00	3.25	3.10	3.90	2.85	2.75	2.55	2.30	2.45	2.80	2.75
18	3.25	3.05	3.20	3.10	3.10	2.85	2.75	2.55	2.30	2.40	3.25	2.75
19	3.15	3.25	3.10	3.60	3.10	2.90	2.95	3.15	2.30	2.90	4.05	2.80
20	3.20	3.50	3.10	3.20	3.10	2.85	2.90	2.75	2.30	2.75	3.10	3.35
21	3.35	3.75	3.05	3.30	3.30	2.85	2.90	2.75	2.25	2.60	2.85	3.35
22	3.20	3.40	3.05	3.30	3.50	2.85	2.80	2.70	2.30	2.75	2.80	2.90
23	3.25	3.25	3.05	3.30	3.50	2.80	2.75	2.60	2.45	2.90	2.80	3.60
24	3.30	3.20	3.10	3.10	3.50	2.80	2.75	2.60	2.60	2.70	2.80	3.05
25	3.15	3.15	3.50	3.15	3.65	2.80	2.75	2.55	2.35	2.65	2.75	2.90
26	3.65	3.10	3.20	3.10	3.50	2.80	2.75	2.55	2.35	2.55	2.80	2.80
27	3.40	3.10	3.10	3.65	3.50	2.80	3.10	2.50	2.30	2.60	2.75	2.80
28	3.25	3.10	3.10	3.10	2.00	3.10	3.10	2.50	2.30	2.60	2.75	2.80
29	3.15	.....	3.15	3.10	3.00	2.95	3.00	2.50	2.30	2.60	2.80	2.70
30	3.15	.....	3.95	3.10	2.95	2.90	2.80	2.50	2.30	2.85	2.85	2.75
31	3.15	.....	3.45	.....	2.95	.....	2.80	2.45	.....	2.95	.....	2.85

Daily gage height, in feet, of North of James River at Glasgow, Virginia, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	1.28	2.30	1.55	3.09	2.00	2.00	1.45	1.30	1.28	1.19	2.80	1.86
2	1.30	1.60	1.55	3.04	1.90	1.90	1.45	1.30	1.25	1.20	2.60	1.75
3	1.32	1.75	1.55	2.92	1.88	1.80	1.46	1.28	1.20	1.21	2.50	1.72
4	1.50	1.70	1.65	2.75	1.88	1.76	1.45	1.74	1.45	1.30	2.30	1.82
5	1.50	1.70	1.75	2.70	1.89	1.68	1.45	6.25	1.70	1.80	2.20	4.30
6	1.45	1.70	1.75	2.68	5.90	1.65	1.50	3.60	1.48	2.40	2.05	3.50
7	1.52	1.65	1.80	2.55	5.88	1.62	1.40	2.88	1.25	2.00	2.02	2.90
8	1.60	1.60	1.80	2.45	4.50	1.58	1.40	2.76	1.15	1.80	1.90	2.50
9	1.50	1.50	1.82	2.40	3.90	1.60	1.40	2.55	1.14	1.65	1.80	2.30
10	1.85	1.50	1.81	2.35	3.80	1.62	1.35	5.75	1.11	1.52	1.82	2.10
11	2.15	1.50	1.80	2.35	3.30	1.62	1.32	8.95	1.08	1.48	1.85	2.15
12	1.65	1.45	1.81	2.35	3.10	1.63	1.32	4.45	1.04	1.60	1.88	2.20
13	1.50	1.55	1.83	2.35	2.77	1.80	1.33	3.40	1.00	1.50	1.85	1.98
14	1.40	1.45	1.85	2.75	2.60	1.92	1.35	3.00	1.00	1.40	1.82	1.70
15	1.55	1.50	1.89	4.48	2.48	1.95	1.35	2.80	1.05	1.40	1.84	1.62
16	3.60	1.30	1.82	4.10	2.38	2.00	1.35	2.40	1.00	1.40	1.86	1.62
17	2.90	1.20	1.86	3.75	2.32	2.05	1.35	2.25	1.00	1.40	1.88	1.72
18	2.52	1.35	1.95	3.15	2.21	2.05	3.00	2.15	1.02	1.38	1.90	1.70
19	2.30	1.50	2.00	3.00	2.10	2.40	2.50	2.00	1.00	5.80	2.40	1.65
20	2.15	1.50	1.95	2.85	2.01	2.55	2.15	1.90	.95	3.65	3.20	1.75
21	2.45	1.70	1.80	2.65	2.27	2.25	1.90	1.70	.98	3.00	2.80	1.70
22	1.40	1.80	1.75	2.32	2.55	2.00	1.70	1.64	1.00	10.75	2.52	1.68
23	1.45	1.90	1.75	2.30	2.85	1.90	2.52	1.52	3.00	5.60	2.50	3.05
24	1.42	1.75	2.14	2.25	2.77	1.80	1.90	1.70	1.90	3.90	2.41	3.40
25	2.00	1.75	2.85	2.28	3.10	1.70	1.90	1.50	1.48	3.60	2.30	2.80
26	2.50	1.70	2.80	2.25	2.70	1.65	1.90	1.48	1.30	2.95	2.18	2.60
27	2.50	1.65	2.58	2.25	2.90	1.60	1.90	1.45	1.25	2.15	2.10	2.42
28	2.45	1.55	2.50	2.12	2.55	1.60	2.00	1.42	1.20	2.50	2.00	2.30
29	2.20	.....	2.08	2.10	2.32	1.58	2.00	1.38	1.20	2.60	1.90	2.12
30	2.20	.....	4.85	2.05	2.25	1.50	1.80	1.30	1.20	2.80	1.92	2.02
31	2.10	.....	4.50	.....	2.10	.....	1.60	1.30	.....	2.90	.....	2.00

Daily gage height, in feet, of James River at Buchanan, Virginia, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	2.50	3.00	2.50	6.95	3.00	3.00	1.90	2.45	2.40	2.20	3.65	3.20
2	2.55	3.00	2.50	5.70	2.90	2.85	1.90	2.20	2.30	2.10	3.55	3.10
3	2.70	2.90	2.60	4.85	2.80	2.70	1.90	2.20	2.20	2.10	3.25	3.00
4	2.60	2.90	2.60	4.40	2.70	2.60	1.90	3.60	2.50	2.60	3.00	3.30
5	2.50	2.80	2.50	4.20	2.60	2.60	1.80	7.30	2.25	2.75	3.00	5.45
6	2.50	2.80	2.50	4.35	4.35	2.60	1.85	5.55	2.20	4.35	3.00	4.45
7	2.40	2.80	2.50	4.15	11.10	2.50	1.90	4.20	2.20	3.95	2.90	4.40
8	2.40	2.80	2.60	3.90	8.80	2.40	1.90	3.95	2.10	3.20	2.90	3.70
9	2.40	2.70	2.60	3.80	7.00	2.40	1.90	4.50	2.10	2.95	2.80	3.70
10	2.40	2.70	2.60	3.80	5.70	2.30	1.90	8.30	2.00	2.70	2.70	3.60
11	3.50	2.55	2.60	4.70	4.95	2.30	1.90	11.55	2.00	2.50	2.70	3.50
12	3.95	2.40	2.60	6.65	4.45	2.30	1.90	6.90	2.00	2.60	2.70	3.40
13	3.55	2.40	2.60	5.50	4.05	2.30	1.80	5.05	1.90	2.50	2.70	3.30
14	3.20	2.40	2.60	5.40	3.75	2.30	1.80	6.00	1.90	2.50	2.90	3.20
15	3.15	2.40	2.60	7.20	3.60	2.30	1.80	4.70	1.90	2.40	2.90	3.10
16	4.20	2.40	2.60	6.35	3.50	2.30	1.80	4.10	1.80	2.40	2.90	3.00
17	4.80	2.30	2.60	5.50	3.50	2.40	1.80	3.60	1.80	2.45	2.90	3.00
18	4.30	2.30	3.55	4.90	3.30	2.40	2.35	3.35	1.80	2.70	2.90	2.90
19	3.70	2.30	4.40	4.40	3.30	2.55	2.50	3.35	1.80	6.45	4.25	2.90
20	3.55	2.30	4.20	4.15	3.50	2.70	2.20	3.05	1.80	4.85	6.30	2.90
21	3.80	2.30	3.75	3.75	3.30	2.60	2.10	2.80	1.80	6.85	5.25	2.80
22	3.85	2.75	3.45	3.55	3.10	2.50	2.30	2.70	2.25	14.10	4.40	2.80
23	3.55	3.30	3.25	3.35	5.00	2.40	2.35	2.55	5.50	8.60	4.25	4.35
24	3.50	3.05	3.10	3.30	5.90	2.40	2.30	2.40	3.70	6.05	4.20	5.60
25	3.70	2.90	4.00	3.30	5.05	2.30	2.50	2.65	3.00	5.00	4.05	4.70
26	3.80	2.80	5.25	3.30	4.70	2.30	2.90	2.50	2.50	4.55	3.75	4.25
27	4.45	2.70	4.45	3.30	4.25	2.15	2.25	2.50	2.40	4.10	3.55	3.85
28	4.10	2.60	4.00	3.25	3.80	2.05	3.40	2.50	2.30	4.00	3.40	3.60
29	3.70	.....	4.30	3.10	3.45	2.00	3.25	2.50	2.30	3.65	3.30	3.50
30	3.55	.....	3.50	3.00	3.30	2.00	2.75	2.50	2.20	3.70	3.20	3.50
31	3.25	.....	3.20	.....	3.20	.....	2.50	2.40	.....	3.90	.....	3.40

List of discharge measurements, 1898.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
				Feet.	*Sec.-feet.*
Feb. 24	Delaware River	Lambertville, N. J.	E. G. Paul	7.85	44,421
Sept. 21	do	do	do	3.30	4,683
Feb. 25	Susquehanna River.	Harrisburg, Pa.	do	6.58	76,250
Mar. 24	do	do	do	15.75	250,485
Mar. 25	do	do	do	14.65	228,374
Mar. 26	do	do	do	10.75	149,589
July 25	do	do	do	.83	5,466
Sept. 22	do	do	do	.92	6,993
Oct. 7	do	do	do	.72	6,121
Jan. 8	Octoraro Creek	Rowlandsville, Md.	Hugh W. Caldwell	3.40	201
Jan. 26	do	do	do	4.00	430
Feb. 12	do	do	do	3.70	360
Feb. 21	do	do	do	4.90	934
Feb. 22	do	do	do	4.10	428
Feb. 23	do	do	do	3.90	339
Mar. 12	do	do	do	3.60	236
May 24	do	do	do	4.10	416
May 28	do	do	do	3.70	362
June 20	do	do	do	4.30	426
June 22	do	do	do	3.50	214
July 5	do	do	do	4.10	424
July 12	do	do	do	3.80	211
July 19	do	do	do	3.80	288
Aug. 3	do	do	do	3.40	225
Aug. 12	do	do	do	3.80	289
Aug. 25	do	do	do	6.40	1,663
Sept. 30	do	do	do	3.50	209
Oct. 6	do	do	E. G. Paul	3.60	182
Oct. 17	do	do	Hugh W. Caldwell	3.30	200
Oct. 22	do	do	do	3.70	287
Nov. 26	do	do	do	4.10	420
Dec. 7	do	do	do	6.40	1,557
Dec. 26	do	do	do	4.20	434
Jan. 26	Patapsco River	Woodstock, Md.	E. G. Paul	4.55	763
Oct. 3	do	do	do	3.60	190
Jan. 27	Patuxent River	Laurel, Md.	do	5.80	359
May 19	do	do	do	4.90	221
Jan. 24	Antietam Creek	Sharpsburg, Md.	do	2.70	427
Aug. 19	do	do	do	3.50	831
Jan. 24	Shenandoah River	Millville, W. Va.	do	2.20	3,001

List of discharge measurements, 1898—Continued.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
				Feet.	*Sec.-feet.*
Aug. 16	Shenandoah River	Millville, W. Va	E. G. Paul	4.30	7,834
Oct. 1	do	do	do	.90	1,001
Jan. 26	Monocacy River	Frederick, Md.	do	7.55	2,352
Aug. 20	do	do	do	6.95	1,605
Jan. 25	Potomac River	Point of Rocks, Md.	do	6.50	33,344
Aug. 19	do	do	do	3.30	14,209
Oct. 3	do	do	do	.65	1,939
May 18	Rock Creek	Park station, D. C.	do	3.20	95
May 7	North River	Glasgow, Va.	D. C. Humphreys.	6.00	6,316
July 19	do	do	do	1.60	426
Dec. 23	do	do	do	3.68	2,869
Feb. 12	James River	Buchanan, Va.	do	2.40	932
June 27	do	do	do	2.05	544
July 30	do	do	do	2.86	1,468
Dec. 23	do	do	do	4.32	3,664
May 12	North Branch of Potomac River.	Cumberland, Md.	E. G. Paul	3.80	1,829
Do.	Wills Creek	do	do	.....	381
May 13	do	do	do	5.00	368
Oct. 2	Antietam Creek	Stonebreakers Mills, Md.	do	1.80	70
Oct. 5	Great Gunpowder River.	One-half mile above Loreley, Md.	do	.....	308

Rating tables.

Lambertville.		Harrisburg.		Rowlandsville.		Woodstock.		Laurel.		Sharpsburg.	
Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*
2.4	2,500	0.0	3,000	2.7	120	3.0	50	2.7	0	1.2	38
2.6	2,750	.5	4,700	2.8	125	3.1	66	2.8	2	1.3	45
2.8	3,250	1.0	7,000	2.9	137	3.2	83	2.9	5	1.4	60
3.0	3,750	1.5	10,100	3.0	150	3.3	100	3.0	10	1.5	80
3.2	4,350	2.0	13,900	3.2	180	3.4	122	3.2	20	1.6	105
3.4	5,200	2.5	18,300	3.4	220	3.5	148	3.4	30	1.7	128
3.6	6,300	3.0	23,400	3.6	270	3.6	173	3.6	42	1.8	171
3.8	7,450	3.5	29,100	3.8	330	3.7	200	3.8	56	1.9	202
4.0	8,800	4.0	35,400	4.0	390	3.8	235	4.0	70	2.0	233
4.2	10,300	4.5	42,750	4.2	480	3.9	270	4.2	86	2.1	264
4.4	11,900	5.0	51,400	4.4	590	4.0	310	4.4	102	2.2	294
4.6	13,600	5.5	61,080	4.6	705	4.1	355	4.6	120	2.3	325
4.8	15,400	6.0	69,930	4.8	815	4.2	400	4.8	140	2.4	356
5.0	17,200	6.5	78,890	5.0	930	4.3	450	5.0	162	2.5	387
5.2	19,050	7.0	87,790	5.2	1,040	4.4	520	5.5	217	2.6	417
5.4	20,950	7.5	96,690	5.4	1,155	4.5	590	6.0	272	2.7	448
5.6	22,860	8.0	105,590	5.6	1,265	4.6	670	6.5	329	2.8	479
5.8	24,780	8.5	114,490	5.8	1,380	4.7	750	7.0	389	2.9	510
6.0	26,700	9.0	123,390	6.0	1,490	4.8	835	7.5	455	3.0	544
6.2	28,620	9.5	132,290	6.2	1,605	4.9	915	8.0	545	3.2	644
6.4	30,540	10.0	141,240	6.4	1,715	5.0	1,000	8.5	655	3.4	766
6.6	32,460	10.5	150,190	6.6	1,830	5.1	1,100	9.0	800	3.6	887
6.8	34,380	11.0	159,140	6.8	1,940	5.2	1,200	9.5	1,025	3.8	1,000
7.0	36,300	11.5	168,090	7.0	2,055	5.3	1,300	10.0	1,400	4.0	1,114
7.5	41,100	12.0	177,040	7.5	2,335	5.4	1,400	10.5	2,084	4.2	1,227
8.0	45,900	12.5	185,990	8.0	2,615	5.5	1,500	11.0	2,674	4.4	1,340
8.5	50,700	13.0	194,940	8.5	2,900	5.6	1,600	.....	.....	4.6	1,454
9.0	55,500	13.5	203,890	9.0	3,180	5.7	1,700	.....	.....	4.8	1,567
9.5	60,300	14.0	212,840	9.5	3,460	5.8	1,800	.....	.....	5.0	1,680
10.0	65,100	15.0	230,740	10.0	3,740	5.9	1,900	.....	.....	.....	.....

Rating tables—Continued.

Port Republic. *a*		Port Republic. *b*		Millville.		Frederick.		Point of Rocks.	
Gage height	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*
1.6	165	1.3	95	0.3	600	3.6	45	0.0	300
1.8	215	1.4	105	.4	620	3.8	90	.2	600
2.0	275	1.5	120	.5	650	4.0	150	.4	1,100
2.2	350	1.6	140	.6	710	4.2	210	.6	1,700
2.4	445	1.7	160	.7	780	4.4	270	.8	2,400
2.6	555	1.8	180	.8	850	4.6	340	1.0	3,100
2.8	700	1.9	210	.9	920	4.8	420	1.2	4,000
3.0	865	2.0	250	1.0	990	5.0	500	1.4	4,900
3.2	1,050	2.2	350	1.2	1,160	5.5	750	1.6	5,800
3.4	1,290	2.4	495	1.4	1,390	6.0	1,020	1.8	6,700
3.6	1,550	2.6	645	1.6	1,650	6.5	1,450	2.0	7,600
3.8	1,860	2.8	795	1.8	1,960	7.0	1,880	2.2	8,600
4.0	2,170	3.0	945	2.0	2,310	7.5	2,310	2.4	9,600
4.2	2,480	3.2	1,060	2.2	2,700	8.0	2,740	2.6	10,650
4.4	2,790	3.4	1,240	2.4	3,100	8.5	3,170	2.8	11,750
4.6	3,100	3.6	1,390	2.6	3,500	9.0	3,600	3.0	12,850
4.8	3,410	3.8	1,535	2.8	3,930	9.5	4,030	3.5	15,500
5.0	3,720	4.0	1,685	3.0	4,370	10.0	4,460	4.0	18,250
5.5	4,495	4.2	1,835	3.2	4,840	10.5	4,890	4.5	21,250
6.0	5,270	4.4	1,980	3.4	5,320	11.0	5,320	5.0	24,050
6.5	6,045	4.6	2,125	3.6	5,800	11.5	5,750	5.5	27,000
7.0	6,820	4.8	2,275	3.8	6,280	12.0	6,180	6.0	30,150
7.5	7,595	5.0	2,425	4.0	6,800	12.5	6,610	6.5	33,200
8.0	8,370	5.2	2,575	4.5	8,200	13.0	7,040	7.0	37,700
8.5	9,145	5.4	2,720	5.0	9,830	13.5	7,470	7.5	42,200
9.0	9,920	5.6	2,870	5.5	11,605	14.0	7,900	8.0	46,700
9.5	10,695	5.8	3,015	6.0	13,430	14.5	8,330	8.5	51,200
10.0	11,470	6.0	3,165	6.5	15,255	15.0	8,760	9.0	55,700
10.5	12,245	6.5	3,535	7.0	17,080	15.5	9,190	9.5	60,200
11.0	13,020	7.0	3,905	.....	.....	16.0	9,620	10.0	64,700

a Rating table for North River, applicable from August 5, 1895, to December 31, 1898.
b Rating table for South River, applicable from August 5, 1895, to December 31, 1898

SOUTHERN ATLANTIC COAST DRAINAGE.

DESCRIPTION OF RIVER STATIONS.

Roanoke station on Roanoke River.—Described on page 25 of Paper No. 15; results for 1897 shown on page 174 of the Nineteenth Annual Report, Part IV. The observer since September 3, 1898, has been Preston Lyons.

Clarksville station on Dan and Staunton rivers.—Described on page 26 of Paper No. 15; results for 1897 shown on page 176 of the Nineteenth Annual Report, Part IV. This station was discontinued on February 26, 1898.

Neal station on Roanoke River.—Described on page 28 of Paper No. 15; results for 1897 given on page 174 of the Nineteenth Annual Report, Part IV.

Tarboro station on Tar River.—Described on page 29 of Paper No. 15; results for 1897 given on page 183 of the Nineteenth Annual Report, Part IV.

Selma station on Neuse River.—Described on page 30 of Paper No. 15; results for 1897 given on page 185 of the Nineteenth Annual Report, Part IV.

Moncure station on Haw River.—This station, established May 6, 1898, is located about 1¾ miles north of Moncure, Chatham County, North Carolina, at the bridge of the Seaboard Air Line, which crosses the river here, and about 2 miles from the junction with the Deep

River to form the Cape Fear. The observer is M. A. Moore, Moncure, Chatham County, North Carolina, who also attends the station on Deep River. The gage is a horizontal rod, well painted, divided into feet and tenths, and securely nailed to the outer side of the guard rail of the bridge on the upstream side. The two-foot mark on the rod is over the center of the second-floor beam from the south end of th second span from the south end of the bridge. The outer rim of the pulley wheel is 0.3 foot from the zero of the gage rod and the distance from the end of the weight to the pointer on the wire rope is 43.45 feet, the gage reading zero when the weight touches the bottom of the stream. The initial point for soundings is a notch cut in the guard rail opposite the south end of the bridge and on the upstream side, the section here being better than that on the downstream side. The channel is straight for some distance above and below the station The velocity is good and uniformly distributed across the stream. Both banks are rather low and somewhat subject to overflow in time of flood. The bed of the stream is of coarse sand and gravel, and is probably not subject to any decided change in high water. The current here is somewhat modified by a fish dam about 150 yards above the bridge. The station is reached by private conveyance from Moncure.

Moncure station on Deep River.—This station, established May 5, 1898, is located about one-fourth of a mile south of Moncure, Chatham County, North Carolina, at the covered wooden bridge of the Seaboard Air Line, which crosses the river here, and about 2 miles above the junction with the Haw River to form the Cape Fear. The observer is M. A. Moore, Moncure, Chatham County, North Carolina, a farmer and also bridge watchman, living about 100 yards from the bridge. The gage is a horizontal rod, well painted, divided into feet and tenths, and securely nailed to the guard rail of the bridge. The zero of the rod is 50 feet south of the north end of the second span of the bridge from the north. The outer rim of the pulley wheel is 3.7 feet from the zero of the rod, and from the end of the weight to the pointer on the wire rope is 45.16 feet, the gage reading zero when the weight touches the bottom of the river. The initial point for soundings is a notch cut in the guard rail opposite the south end of the bridge and on the downstream side. The channel is straight for some distance above and below the station. The velocity is not great but sufficient for the purpose, and is well distributed across the stream. Both banks are rather low and subject to overflow. The bed of the river is of fine sand and mud, and is probably subject to change in high water.

Fayetteville station on Cape Fear River.—Described on page 31 of Paper No. 15; results for 1897 given on page 187 of the Nineteenth Annual Report, Part IV.

Salisbury station on Yadkin River.—Described on page 32 of Paper No. 15; results for 1897 given on page 194 of the Nineteenth Annual Report, Part IV.

Norwood station on Yadkin (Pedee) River.—Described on page 33 of Paper No. 15; results for 1897 given on page 194 of the Nineteenth Annual Report, Part IV.

Catawba station on Catawba River.—Described on page 34 of Paper No. 15; results for 1897 shown on page 204 of the Nineteenth Annual Report, Part IV. The observer since July 2, 1898, has been C. A. Reid, jr.

Rockhill station on Catawba River.—Described on page 35 of Paper No. 15; results for 1897 shown on page 204 of the Nineteenth Annual Report, Part IV. The rating table for this station, printed on page 213 of the above report, does not fairly represent the conditions prevailing from February to December, 1897. The drought that began in August of that year and continued until the latter half of October was the most severe in the history of the State, if not in the history of the South generally, and the streams attained a lower stage of flow than ever before, according to the testimony of those living near them. Also the level of the underground waters, as shown by the wells and springs, was lower than for a quarter of a century. As shown by the gage heights of the rivers, all of them during September and October of this year reached a stage of flow lower than at any time during the year or during the preceding years. The rating table and the gage heights for the upper station on this river show that the minimum flow for this year was during this period. It therefore appears that the same should be true for this lower station, but instead the rating table makes the minimum flow for the year come in January, which is out of accord not only with the abnormal conditions prevailing at this time, but with those of the normal year.

Gaffney station on Broad River (a tributary of Santee River).—This station has been changed from the locality described on page 36 of Paper No. 15. The gage wire was broken on October 1, 1898, and on October 25 the gage was moved to Gaffney Ferry, about 200 yards above the railroad bridge, where there is a better section and where nearly all the measurements have been taken. The gage was moved in the following manner: A small temporary gage was set up at the ferry in order that the rise or fall of the river might be determined and allowed for in the final setting of the gage in its new position. The wire to the gage at the railroad bridge was then replaced and the gage reading taken. The rod was then removed and taken to the ferry. The temporary gage was read again and with the same result as before, indicating that the water was at a stand. This being the case, all that was necessary to set the gage was to make the reading in its new position the same as in its old position. From the fact, however, that in its old position the water had frequently fallen below the zero of the gage, it was thought best to change the position of the rod somewhat, and accordingly the zero of the rod was moved downward 2 feet. The reading at the bridge was 0.90 foot; the new reading was therefore 2.90 feet. The observations from January 1 to September 30 have been adjusted to the new zero by adding 2 feet.

The rod is securely nailed and braced to a large overhanging tree just east of Gaffney Ferry, on the south side of the river, and the rod is 72 feet west of a bench mark consisting of a large steel nail

driven in a notch cut in the root of a large elm tree on the south side of the river, just to the east of the road leading to the ferry and about 30 feet from the river bank. The zero of the rod is 13.29 feet below this nail. The bottom here is sand, with some mud, and quite smooth. The velocity is quite rapid, well distributed all the way across, and the channel is straight for some distance above and below the station. The services of the ferryman, John W. Gaffney, Gaffney, South Carolina, were obtained to take charge of the gage.

Alston station on Broad River (tributary to Santee River).—Described on page 37 of Paper No. 15; results for 1897 shown on page 215 of the Nineteenth Annual Report, Part IV.

Waterloo station on Saluda River.—Described on page 38 of Paper No. 15; results for 1897 shown on page 221 of the Nineteenth Annual Report, Part IV.

Madison station on Tugalo River.—Established July 19, 1898, at Cooks Ferry, about half a mile from Madison, South Carolina, and 1 mile below the Southern Railway bridge on Tugalo River. S. C. Cobb, a farmer living in Georgia, about 300 yards from the ferry, was employed on July 19, 1898, as observer; but the discharge measurements were begun on May 26, 1898. The gage is a 2 by 4 inch scantling, 10 feet long, graduated to feet and tenths, and nailed to a sycamore tree on the right bank at the ferry landing. Higher stages are noted on the sycamore above the rod by measuring up from the top of rod. Measurements are made from a boat held in place by the ferry rope stretched across the river. The bench marks are on the left bank of river, the first being on a willow tree at the bateau landing, and consisting of three large nails 3 feet above zero of gage; the second is on the same tree, being one nail 6 feet above zero of gage; and the third is a large nail in a sycamore at the ferry landing 12 feet above the zero of gage.

Calhoun Falls station on Savannah River.—Described on page 39 of Paper No. 15; results for 1897 are shown on page 223 of the Nineteenth Annual Report, Part IV. The station was discontinued on August 9, 1898.

Augusta station on Savannah River.—Observations of river height have been maintained since 1875 by the city of Augusta at the city highway bridge. The results have been printed in the volumes entitled Stages of Water at River Stations, prepared by the United States Weather Bureau. Those for 1875 to 1889 are given in Part III, those for 1890 to 1892 in Part IV, and for 1893 to 1895 in Part V. The gage consists of a vertical timber fastened to the pier and graduated to feet and inches. Readings are made four times a day, usually at 6 a. m., 12 m., 6 p. m., and 9 p. m. The 6 a. m. readings are those used by the Weather Bureau. The observer is J. M. Youngblood, keeper of the city bridge. The gage heights as given in the following pages have been changed from feet and inches to feet and tenths, and have been averaged for the day. The zero of this gage is the low water of 1835. The highest water recorded was on September 11, 1888, at 38.7 feet.

At that time the entire city was submerged, ten persons were drowned, and property was damaged to the amount of $2,000,000.[1]

The floods of this river have been investigated under the direction of the Corps of Engineers, United States Army, and reports prepared by George W. Brown, assistant engineer. The first of these, dated February 11, 1889, was printed, with maps, as House Ex. Doc. No. 213, Fifty-first Congress, first session; also given, with few maps, in the Report of the Chief of Engineers, United States Army, 1890, page 1340. A later report, dated June 10, 1890, also prepared by Mr. George W. Brown, was printed as Ex. Doc. No. 255, Fifty-first Congress, second session. In this report is given a rating table, showing the probable discharge of the river at heights on the gage of from 5 to 40 feet. On page 17 of this latter document is shown the run-off in cubic feet per second per square mile for various portions of the drainage basin. There is also given a table of distances and elevations and the slope of the river, as well as a description of the character of the drainage basin.

From the figures in the above-named reports a computation was made by Cyrus C. Babb of the fluctuations of flow of Savannah River, the results being published in the Fourteenth Annual Report, Part II, of the United States Geological Survey, page 147, and relating to the years 1884 to 1891, inclusive. A discussion of the results is also given in Transactions American Society of Civil Engineers, Volume XXIII, page 332. The later discharge measurements, made during 1897 and 1898 by Prof. B. M. Hall and others, have furnished material for the construction of a new rating table. A comparison of this with earlier, less accurate tables may be of interest in this connection.

Rating tables of Savannah River at Augusta, Georgia.

Gage height.	Discharge in second-feet.		
	Brown. *a*	Babb. *b*	Hall. *c*
Feet.			
4.0	.....	1,900	2,350
5.0	3,000	2,700	3,100
6.0	4,000	3,600	4,020
7.0	5,210	4,900	5,400
8.0	6,600	6,700	7,200
9.0	8,400	8,500	9,340
10.0	10,400	10,400	11,800
11.0	12,600	12,800	14,620
12.0	14,900	14,800	17,750
13.0	17,300	17,300	21,100
14.0	20,000	20,100	25,000
15.0	22,700	22,800	29,300
16.0	25,500	25,300	33,600
17.0	28,700	28,500	38,000
18.0	32,100	31,900	42,400
20.0	39,000	39,000	51,200
22.0	.....	46,800	60,000
24.0	.....	55,000	68,800
26.0	.....	62,700	77,600
28.0	.....	76,500	86,400
30.0	89,000	89,200	.....

a By George W. Brown, assistant engineer, Corps of Engineers, United States Army, published in Annual Report of Chief of Engineers, United States Army, 1890, page 1341.

b By Cyrus C. Babb, assistant hydrographer, United States Geological Survey. Results published in Fourteenth Annual Report of United States Geological Survey, Part II, page 147.

c By B. M. Hall, resident hydrographer, United States Geological Survey, from gagings made in 1897 and 1898.

[1] Description of River Gages, Part V, United States Weather Bureau, p. viii.

ing following these dates. In this way the estimated discharge at Almon was referred to the readings on the gage at Macon and a new discharge table computed in which the heights at Macon are given, and assume discharges at Almon are set opposite. The application of such a table involves the assumption that the fluctuations at Almon are coincident with those at Macon. The following values have been obtained:

Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*
−1.00	80	3.00	528	7.00	1,070	10.00	1,478	14.00	2,022
0.00	122	4.00	664	8.00	1,206	11.00	1,614	16.00	2,294
1.00	257	5.00	800	9.00	1,342	12.00	1,750	18.00	2,566
2.00	392	6.00	936						

Macon station on Ocmulgee River.—Described on page 44 of Paper No. 15; result for 1897 shown on page 230 of the Nineteenth Annual Report, Part IV.

TABLES OF DAILY GAGE HEIGHT.

Daily gage height, in feet, of Roanoke River at Roanoke, Virginia, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	1.15	2.00	0.95	2.25	0.80	1.35	0.95	1.85	1.05	1.30	1.85	1.30
2	1.15	1.90	.95	2.00	.75	1.30	.90	1.90	.95	1.40	1.80	1.20
3	1.15	1.85	1.00	1.85	.75	1.20	.85	1.95	.95	2.08	1.75	1.50
4	1.10	1.85	1.00	1.70	.70	1.15	.85	2.50	1.05	2.00	1.75	2.00
5	1.10	1.80	1.10	1.65	.70	1.10	.85	3.10	2.04	2.68	1.70	3.40
6	1.00	1.80	1.00	1.60	3.80	1.05	.85	2.45	2.00	3.00	1.75	2.50
7	.95	1.70	.95	1.60	4.90	1.05	.80	1.95	2.08	2.35	1.70	2.25
8	.95	1.65	.95	1.50	3.25	1.00	.75	1.90	1.07	2.00	1.70	2.00
9	.90	1.60	.90	1.50	2.50	1.00	.60	1.90	1.07	1.90	1.65	1.90
10	.90	1.60	.85	1.40	2.10	.95	.55	1.95	1.07	1.80	1.65	1.60
11	.85	1.55	.80	1.40	2.00	.90	.45	1.95	1.07	1.70	1.60	1.50
12	.85	1.50	.75	1.35	2.20	.90	.45	1.90	1.05	1.65	1.60	1.50
13	.85	1.50	.75	1.30	1.65	.95	.45	1.90	1.03	1.60	1.55	1.50
14	.95	1.40	.75	1.65	1.50	1.00	.45	2.60	1.01	1.55	1.50	1.45
15	1.30	1.35	.70	1.60	1.45	1.25	.50	2.45	1.01	1.50	1.45	1.40
16	1.40	1.30	.70	1.55	1.45	1.30	.50	2.20	1.01	1.50	1.40	1.35
17	1.35	1.20	.70	(a)	1.40	1.40	.45	1.90	1.50	1.40	1.55	1.65
18	1.25	1.15	.65	(a)	1.30	1.40	1.15	1.75	1.00	1.60	1.50	1.65
19	1.20	1.10	.65	(a)	1.25	1.50	1.20	1.50	1.00	3.50	1.95	1.65
20	1.15	1.10	.65	(a)	1.20	1.45	1.10	1.30	1.00	2.60	2.20	1.60
21	2.00	1.00	.65	(a)	1.15	1.40	.95	1.25	1.05	2 60	2.00	1.60
22	2.50	1.00	.60	(a)	1.55	1.60	1.75	1.20	1.40	5.00	1.90	1.55
23	2.35	1.00	.60	(a)	3.10	1.70	1.75	1.10	3.55	4.45	1.85	2.80
24	2.35	.95	.70	(a)	2.95	1.60	1.60	1.10	2.20	3.00	1.75	2.50
25	2.40	.95	1.50	(a)	2.40	1.55	1.45	1.00	1.85	2.75	1.65	2.35
26	2.40	.95	1.75	(a)	1.95	1.50	1.25	.95	1.70	2.30	1.65	2.20
27	2.35	.90	2.00	(a)	1.62	1.35	1.15	.95	1.50	2.00	1.50	2.00
28	2.20	.90	2.50	(a)	1.50	1.15	1.35	1.10	1.50	1.90	1.40	1.90
29	2.15	.....	2.75	(a)	1.45	1.00	1.40	1.10	1.40	1.90	1.50	1.85
30	2.15	.....	3.05	(a)	1.40	1.00	1.55	1.15	1.30	1.95	1.40	1.80
31	2.15	.....	2.75	(a)	1.40	.....	1.55	1.15	.....	1.95	.....	1.80

a April 17–30, no observations.

Daily gage height, in feet, of Dan River at Clarksville, Virginia, for 1898. (a)

Day.	Jan.	Feb.	Day.	Jan.	Feb.	Day.	Jan.	Feb.	Day.	Jan.	Feb.
1	0.70	0.87	9	1.00	0.90	17	0.75	0.55	25	2.70	1.02
2	.68	.72	10	.80	1.25	18	1.45	.53	26	3.92	.95
3	.65	.69	11	.70	1.12	19	1.05	.59	27	2.45	.....
4	.78	.65	12	1.10	1.02	20	.95	.55	28	2.05	.....
5	.95	.58	13	.89	.88	21	.80	.68	29	1.70	.....
6	1.05	.55	14	.89	.76	22	.74	.75	30	1.28	.....
7	1.00	.62	15	.70	.70	23	.68	.88	31	.95	.....
8	1.00	.75	16	.65	.60	24	1.25	.95			

a Station discontinued February 26.

Daily gage height, in feet, of Staunton River at Clarksville, Virginia, for 1898. (a)

Day.	Jan.	Feb.	Day.	Jan.	Feb.	Day.	Jan.	Feb.	Day.	Jan.	Feb.
1	0.35	0.49	9	0.60	0.51	17	0.48	0.27	25	2.10	0.74
2	.43	.40	10	.42	.65	18	1.05	.25	26	3.25	.65
3	.39	.43	11	.38	.60	19	.70	.33	27	2.08	.....
4	.50	.39	12	.69	.54	20	.65	.33	28	1.63	.....
5	.65	.33	13	.50	.51	21	.42	.43	29	1.25	.....
6	.70	.27	14	.50	.49	22	.47	.48	30	.88	.....
7	.71	.35	15	.38	.38	23	.43	.54	31	.65	.....
8	.71	.48	16	.39	.34	24	.65	.65			

a Station discontinued February 26.

Daily gage height, in feet, of Roanoke River at Neal, North Carolina, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	8.60	8.60	3.40	10.00	6.10	11.20	3.20	7.80	5.30	13.50	16.80	7.50
2	7.40	7.30	3.50	15.30	5.40	9.80	3.60	7.20	5.30	11.00	17.30	8.10
3	6.40	6.70	3.40	15.20	4.70	8.60	3.40	6.70	4.80	9.10	15.00	8.30
4	5.70	5.80	3.50	12.80	4.30	7.10	2.70	6.20	3.80	7.50	12.30	9.00
5	4.80	4.90	4.30	10.60	4.00	5.67	1.90	5.30	3.30	6.10	10.10	10.50
6	4.20	4.10	7.40	9.90	4.30	4.40	1.85	4.50	2.70	5.40	8.50	15.70
7	4.00	3.60	9.70	13.00	6.70	3.80	4.20	3.50	2.30	5.80	7.70	20.90
8	4.40	4.00	9.20	15.40	15.95	3.30	4.20	5.65	7.50	12.80	6.90	20.10
9	4.60	4.40	8.10	14.80	20.85	3.00	3.90	6.90	8.90	13.00	6.80	17.50
10	4.60	4.80	6.90	11.50	22.51	2.90	5.80	5.90	8.60	10.40	6.70	14.80
11	4.43	4.90	6.00	9.80	22.51	2.70	5.90	4.70	7.90	8.10	6.20	12.70
12	4.50	4.80	5.40	8.30	20.00	2.30	5.90	4.10	5.50	6.40	5.70	10.90
13	4.68	4.70	4.90	7.30	16.95	2.20	4.80	4.60	3.80	5.30	5.30	9.50
14	4.80	4.70	4.80	7.40	14.20	2.10	5.15	5.30	2.60	4.60	5.30	8.50
15	4.80	4.40	5.00	8.40	12.10	2.40	4.40	9.20	2.10	4.20	5.50	7.70
16	4.85	4.20	5.00	7.90	11.32	4.20	3.80	11.70	1.80	3.80	5.40	7.10
17	4.90	3.90	4.80	7.80	12.50	6.90	2.50	15.70	1.60	3.50	5.50	6.50
18	4.60	3.70	4.60	8.20	12.75	9.00	3.30	12.50	1.40	3.20	5.70	5.75
19	4.30	3.60	4.40	7.90	11.90	12.30	6.90	8.90	1.35	3.20	6.00	5.50
20	4.30	3.40	4.20	7.10	9.90	15.00	7.80	6.60	1.20	3.80	6.90	5.90
21	4.10	3.40	4.00	6.40	8.30	14.70	8.60	6.00	1.10	6.30	9.00	6.70
22	4.20	3.80	3.80	5.70	6.50	15.80	7.80	5.70	1.00	11.80	11.10	7.30
23	5.10	4.50	3.60	5.20	5.60	13.50	6.15	7.80	1.20	10.40	10.80	8.20
24	6.90	5.00	3.50	4.90	10.60	10.20	4.90	6.80	2.00	12.10	9.80	9.50
25	7.40	4.90	3.45	4.80	21.61	7.40	4.60	5.30	21.28	22.30	9.20	14.80
26	7.30	4.60	3.40	5.50	22.66	5.10	5.90	4.20	22.73	22.10	9.30	17.80
27	8.50	4.20	3.50	8.10	22.20	4.00	7.25	3.30	23.88	20.98	8.90	15.20
28	12.00	3.80	4.10	9.40	20.60	3.20	6.90	4.80	23.20	16.50	7.90	12.75
29	13.50	.....	4.80	8.50	18.30	2.90	5.30	4.70	20.60	14.30	7.00	10.80
30	12.00	.....	5.10	7.20	16.00	3.15	5.80	5.00	17.00	12.40	7.20	9.50
31	10.10	.....	6.00	.....	13.30	.....	8.10	4.80	.....	11.20	.....	8.00

Daily gage height, in feet, of Tar River at Tarboro, North Carolina, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	3.40	3.30	1.80	7.30	4.50	5.70	1.80	1.20	8.30	1.60	1.70	4.70
2	3.00	3.25	1.65	9.20	3.70	6.10	1.10	2.15	6.30	1.20	2.20	5.30
3	2.90	3.10	1.55	8.90	3.40	5.00	.90	2.80	4.10	.80	2.30	5.20
4	2.70	2.80	1.70	7.00	2.85	4.10	.60	4.00	3.20	1.20	1.80	6.20
5	2.40	2.60	3.20	5.90	2.50	3.00	.50	3.20	3.10	1.30	1.70	8.50
6	2.20	2.40	5.00	6.20	2.30	2.40	1.90	2.30	2.80	1.40	2.90	11.00
7	2.25	2.30	7.80	8.00	3.00	2.00	7.50	1.80	2.60	1.30	2.50	12.50
8	2.12	2.30	7.00	9.80	4.60	1.70	9.90	1.60	2.10	1.20	2.60	13.00
9	2.00	2.40	4.90	9.10	7.10	1.50	9.60	1.30	2.60	1.60	2.70	11.30
10	1.90	2.20	4.00	6.40	7.80	1.30	8.50	1.00	3.20	1.50	2.90	9.40
11	2.00	2.10	3.70	5.50	6.50	1.10	11.20	.90	2.60	1.60	2.30	7.00
12	2.05	2.00	3.50	5.10	4.90	1.00	11.70	1.50	1.70	1.50	2.80	5.70
13	2.30	1.90	3.20	4.50	4.10	.80	10.70	2.10	1.50	1.40	1.50	5.00
14	2.75	1.90	2.90	4.10	4.00	1.50	8.80	4.10	1.30	1.10	1.40	4.50
15	2.70	2.00	3.60	4.00	3.60	1.00	7.90	4.20	1.00	1.00	1.60	4.10
16	2.60	1.70	5.00	3.80	3.30	1.90	6.80	3.40	.80	.80	1.70	3.60
17	2.40	1.70	5.80	3.50	5.95	3.30	5.20	2.40	.70	.50	2.10	3.40
18	2.90	1.60	4.70	3.30	8.40	5.60	4.30	2.30	.60	.70	2.30	3.10
19	3.00	1.55	4.20	3.10	9.80	5.40	4.20	2.10	.50	.60	2.50	3.20
20	2.73	1.50	4.00	2.80	9.00	5.50	3.70	2.50	.50	2.60	4.30	3.30
21	2.60	1.60	3.60	2.60	7.20	6.70	4.20	5.30	.50	3.00	4.90	3.70
22	2.60	2.80	3.40	2.40	5.70	6.30	3.15	6.50	.40	2.80	5.50	5.00
23	2.70	2.40	3.00	2.20	4.60	5.30	2.80	6.00	.60	2.30	4.30	5.70
24	2.55	2.50	2.70	2.00	5.10	4.10	2.40	5.30	4.70	1.90	3.70	6.30
25	2.70	2.45	2.40	1.90	8.90	3.10	2.20	5.50	7.80	2.30	3.40	6.00
26	3.00	2.30	2.50	2.30	11.00	2.50	1.90	4.60	6.20	2.00	3.20	5.60
27	3.95	2.00	2.40	2.90	12.80	2.00	2.00	2.80	4.00	2.70	3.20	5.00
28	5.90	1.70	2.30	4.20	13.70	2.30	1.50	3.20	2.80	2.50	2.90	4.50
29	5.40	.....	2.30	5.30	12.40	2.50	1.40	4.50	2.20	2.80	3.00	4.20
30	4.20	.....	2.20	5.20	9.10	2.70	1.30	8.80	2.10	2.70	3.70	3.80
31	3.50	.....	2.50	.....	6.50	.....	1.30	8.90	.....	1.30	.....	3.50

Daily gage height, in feet, of Neuse River at Selma, North Carolina, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	1.70	1.30	1.00	11.40	1.50	2.70	0.50	0.70	6.00	0.30	3.00	2.50
2	1.70	1.30	1.00	10.20	1.20	2.00	.50	.80	5.80	.30	3.60	3.00
3	1.50	1.30	1.00	6.70	1.00	1.40	.60	1.10	1.80	.20	2.00	2.80
4	1.30	1.30	1.40	6.00	.80	1.00	.70	1.00	1.00	.30	1.60	7.30
5	1.20	1.30	1.50	7.20	.60	.90	.70	.60	4.50	.50	1.20	11.30
6	1.10	1.20	1.80	10.70	.80	.80	3.00	.50	3.20	.60	1.20	11.40
7	1.00	1.10	8.30	8.00	4.00	.70	5.90	.50	4.10	.70	1.20	10.70
8	.90	1.10	3.70	7.00	6.90	.60	6.00	.50	3.40	2.00	1.30	5.50
9	1.20	1.10	3.20	6.00	5.40	.50	5.80	.50	2.10	1.00	1.40	3.10
10	1.30	1.00	2.00	2.90	4.10	.50	5.30	.60	3.40	1.10	1.40	3.00
11	1.00	1.10	2.50	2.80	3.00	.50	5.00	.50	3.00	1.10	1.50	3.00
12	1.00	1.00	1.70	2.70	3.60	5.00	2.50	1.80	2.80	1.20	1.60	3.20
13	1.20	1.00	1.60	2.00	2.80	4.00	2.00	3.20	2.40	1.30	1.70	3.30
14	1.50	1.00	1.80	2.00	2.00	3.40	2.00	3.30	2.00	1.00	1.90	2.30
15	1.50	1.00	2.80	1.80	8.90	3.00	1.90	3.40	1.80	.80	2.00	1.80
16	1.20	1.00	5.10	1.80	8.00	2.00	1.80	3.00	1.00	.60	2.00	1.60
17	1.30	1.00	6.00	1.70	7.00	1.40	1.50	2.80	1.00	.40	2.60	1.50
18	1.60	1.00	5.00	1.50	5.40	1.50	2.00	2.80	1.00	.90	3.00	1.50
19	1.30	.80	4.20	1.40	3.60	1.80	4.00	1.30	1.00	1.40	5.40	1.40
20	1.30	1.00	3.70	1.30	2.70	2.00	7.00	9.60	1.10	1.80	5.80	1.60
21	1.20	1.00	2.00	1.20	2.00	2.20	5.00	10.40	1.20	1.90	5.00	2.30
22	1.60	1.80	1.70	1.10	3.00	2.00	2.70	6.30	1.30	2.30	4.50	2.40
23	1.40	2.50	1.40	1.20	5.00	1.80	2.00	2.60	4.00	1.90	3.00	2.40
24	1.30	1.80	1.20	1.30	9.00	1.00	1.00	2.50	12.00	1.50	2.80	2.50
25	1.40	1.40	2.00	1.50	10.00	.90	.90	2.80	13.00	1.60	2.20	2.30
26	3.50	1.30	2.50	1.70	11.00	.50	.80	1.60	9.40	1.80	2.00	2.40
27	7.00	1.20	1.80	2.00	7.00	.50	.80	1.80	6.10	1.60	1.90	2.00
28	5.80	1.00	2.00	3.70	5.50	.50	.70	8.90	1.00	1.20	1.80	1.70
29	3.40	.....	3.00	5.00	4.00	.50	.70	5.40	1.00	1.00	2.00	1.60
30	2.30	.....	7.00	4.20	3.50	.40	.70	9.10	.80	1.40	2.50	1.50
31	1.90	.....	9.00	.....	3.00	.....	.70	9.00	.....	2.60	.....	1.40

Daily gage height, in feet, of Haw River at Moncure, North Carolina, for 1898.

Day.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	.....	2.16	1.88	1.88	4.12	1.60	5.34	3.24
2	.....	2.10	1.65	1.96	3.18	1.48	4.28	2.88
3	.....	1.92	1.60	1.86	2.38	1.66	3.44	2.52
4	.....	1.85	1.40	1.80	7.40	1.38	2.62	6.62
5	.....	1.50	1.20	1.60	11.88	2.00	2.55	7.44
6	1.30	1.60	1.80	1.60	7.78	2.86	2.12	6.48
7	5.00	1.50	7.38	1.62	5.22	2.94	2.10	5.20
8	4.50	1.52	3.12	1.50	5.46	2.86	3.00	4.26
9	3.65	1.60	2.30	1.22	4.45	1.72	2.76	3.28
10	3.00	1.50	1.90	1.20	3.74	1.48	2.25	3.16
11	2.50	1.44	2.00	1.30	2.82	1.54	2.42	2.94
12	2.23	1.40	1.38	1.76	2.10	1.60	2.12	2.25
13	1.87	1.40	1.40	2.70	2.04	1.52	2.38	2.54
14	3.10	1.30	1.70	5.98	1.64	1.50	2.67	2.40
15	2.60	2.10	1.85	5.30	1.65	1.51	3.24	2.36
16	2.00	3.10	1.60	3.00	1.60	1.34	3.00	2.22
17	2.30	1.70	1.60	2.94	1.62	1.23	5.23	2.20
18	2.20	1.70	5.60	3.86	1.65	1.66	6.44	2.34
19	2.22	2.30	3.40	10.30	1.62	2.65	6.08	2.12
20	2.00	2.96	4.10	15.85	1.64	1.27	5.62	2.78
21	1.80	3.34	2.44	14.92	1.46	1.94	4.28	2.41
22	1.74	2.60	1.92	10.64	1.44	7.64	3.84	2.22
23	1.60	2.10	4.98	7.25	11.35	5.56	3.02	3.46
24	8.20	1.22	2.80	5.18	9.14	3.28	2.84	3.21
25	6.14	1.30	2.34	3.32	5.28	2.42	2.06	3.34
26	4.46	1.64	2.12	2.14	4.00	2.50	2.00	2.78
27	4.00	1.52	1.90	2.18	2.64	2.14	2.48	2.37
28	3.10	1.58	2.38	2.25	2.32	2.22	2.92	2.30
29	2.42	1.85	2.10	2.38	1.88	1.88	2.58	2.48
30	2.00	1.90	2.16	7.14	1.52	7.16	2.92	2.36
31	2.00	.....	1.98	4.97	.....	9.98	.....	2.34

Daily gage height, in feet, of Deep River at Moncure, North Carolina, for 1898.

Day.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	.....	1.75	1.76	1.12	3.82	1.52	5.72	2.95
2	.....	1.50	1.53	2.00	3.50	1.92	4.89	3.27
3	.....	1.62	1.34	1.80	2.64	1.88	3.22	3.20
4	.....	1.50	1.20	2.00	4.84	1.54	2.78	7.90
5	1.96	1.42	1.14	1.98	12.62	2.92	2.44	9.49
6	1.90	1.20	2.80	1.52	8.67	2.84	2.14	6.34
7	2.30	1.25	7.80	1.50	7.14	2.74	3.92	5.42
8	3.50	1.20	4.52	1.24	5.72	2.22	3.64	4.60
9	3.70	1.24	2.90	1.22	5.88	1.68	2.98	3.14
10	2.74	1.20	2.16	1.20	4.22	1.56	2.76	3.00
11	2.40	1.14	3.60	1.46	3.40	1.54	2.51	2.84
12	2.00	1.54	2.40	1.50	2.48	1.51	2.16	2.32
13	1.74	1.20	1.72	2.66	2.08	1.50	3.28	2.30
14	2.65	1.22	1.84	8.12	1.85	1.54	2.76	2.28
15	2.20	1.30	1.72	12.10	1.08	1.52	2.52	2.25
16	2.10	1.36	1.78	3.82	1.98	1.36	3.51	2.26
17	1.94	2.10	1.75	2.68	1.67	1.32	2.13	2.12
18	2.00	1.94	4.00	4.88	1.52	1.92	5.54	2.25
19	2.10	1.82	2.74	9.00	1.50	3.56	6.28	2.30
20	1.98	2.24	2.86	19.10	1.56	3.22	4.94	2.10
21	1.76	2.65	2.12	18.84	1.48	2.42	4.06	2.54
22	1.64	2.98	1.16	14.13	1.19	8.98	3.76	2.32
23	1.50	2.38	4.22	9.62	2.22	6.00	2.96	4.18
24	6.20	1.94	3.14	5.37	10.44	3.56	2.48	3.70
25	6.54	1.72	2.32	3.12	4.56	3.44	2.21	3.28
26	4.96	1.35	1.94	3.00	3.65	2.98	2.05	3.22
27	3.48	1.36	1.98	2.57	2.68	2.21	2.34	2.48
28	2.28	1.22	1.90	3.30	2.14	2.01	2.24	2.76
29	2.20	1.24	1.82	3.52	1.96	1.99	2.31	2.72
30	1.98	1.78	1.88	6.73	1.80	6.70	3.10	2.40
31	1.70	.....	1.82	5.58	.....	8.76	.....	2.26

Daily gage height, in feet, of Cape Fear River at Fayetteville, North Carolina, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	5.00	5.00	3.50	21.00	6.60	3.20	2.00	6.00	10.30	2.90	14.00	6.10
2	4.90	4.90	3.20	17.30	5.50	3.00	2.00	7.00	9.60	2.50	9.30	6.90
3	4.50	4.80	3.50	11.00	5.00	3.00	1.50	7.00	7.20	2.40	7.10	6.70
4	4.30	4.40	3.50	9.40	4.30	2.70	1.20	6.40	5.70	2.50	5.50	8.40
5	3.70	4.00	7.00	6.00	4.10	2.30	1.00	5.20	14.00	2.40	4.70	16.00
6	3.70	3.90	20.50	12.80	3.80	1.90	5.10	5.00	18.80	2.50	4.20	18.00
7	3.60	3.80	17.70	21.50	3.10	1.40	12.00	4.10	14.00	5.50	3.80	14.60
8	4.00	3.60	11.00	15.30	8.00	1.20	16.20	3.00	12.50	5.60	5.40	11.80
9	3.60	3.50	8.70	11.70	7.00	1.10	12.40	3.00	13.20	4.20	5.00	9.00
10	3.50	3.40	7.90	8.00	6.30	1.20	10.20	2.60	10.00	3.40	4.80	7.00
11	3.40	3.40	5.80	7.00	5.40	1.10	12.50	2.30	8.70	2.70	4.30	5.50
12	3.30	3.50	5.20	6.10	4.50	1.10	8.00	3.70	6.50	2.30	3.70	5.30
13	3.40	3.50	4.90	5.90	4.00	1.20	6.00	5.00	5.00	2.00	3.50	5.30
14	3.60	3.40	5.00	5.70	3.70	1.30	5.10	9.40	4.30	1.90	3.90	5.30
15	3.80	3.20	5.10	5.40	5.00	1.30	5.10	16.00	4.10	1.80	4.30	5.00
16	3.60	2.90	8.00	5.40	4.90	2.50	5.50	14.00	3.80	1.80	6.00	5.00
17	3.70	2.90	9.20	5.60	5.10	3.90	5.50	10.00	3.60	1.50	7.00	4.80
18	3.60	2.90	7.70	5.40	4.70	4.30	4.10	7.00	3.40	1.30	9.80	4.60
19	3.70	3.10	6.20	4.70	4.20	3.90	6.00	9.20	3.10	2.00	10.20	4.70
20	3.80	4.50	5.50	4.40	4.00	4.00	5.50	22.20	2.90	5.00	11.00	4.60
21	3.60	5.30	5.00	4.20	3.50	7.00	5.50	29.00	2.50	5.00	12.20	5.30
22	4.10	5.70	5.00	4.00	3.00	7.00	4.20	29.20	2.20	4.50	9.60	6.10
23	4.40	6.00	4.70	3.90	3.00	5.50	3.60	23.50	2.50	10.00	7.80	8.00
24	4.40	5.50	4.50	4.10	2.90	4.30	10.00	18.00	15.00	9.80	5.60	7.30
25	4.40	5.10	4.20	4.40	12.00	3.20	7.00	10.30	14.00	6.00	5.10	7.00
26	5.50	4.50	5.00	7.20	11.40	2.70	6.00	6.00	9.80	4.50	5.00	6.40
27	14.00	4.10	6.00	10.40	9.00	2.20	4.60	6.10	7.00	4.70	5.10	5.50
28	11.00	3.80	5.60	10.70	6.70	1.70	4.10	6.20	5.00	4.50	4.70	5.30
29	9.20	.....	4.70	12.00	5.00	1.60	4.00	7.00	3.90	3.60	4.40	5.10
30	6.50	.....	4.30	9.60	4.00	2.10	3.90	8.50	3.40	3.50	4.70	4.90
31	5.30	.....	14.80	.....	3.50	.....	4.00	11.00	.....	10.00	.....	4.70

Daily gage height, in feet, of Yadkin River at Salisbury, North Carolina, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	2.00	2.00	1.70	4.70	1.80	1.80	1.70	1.80	2.30	1.80	2.40	1.70
2	2.00	2.00	1.70	3.00	1.80	1.80	1.70	1.70	2.00	1.80	2.40	1.70
3	2.00	2.00	1.80	2.80	1.80	1.70	1.50	2.00	1.80	1.90	2.00	1.70
4	2.00	1.90	2.20	2.30	1.80	1.70	1.30	3.00	2.00	2.20	1.80	2.30
5	2.00	1.90	2.10	2.70	2.60	1.80	1.90	3.10	4.50	3.65	1.80	4.80
6	1.90	1.90	2.00	2.70	2.00	1.70	1.80	3.00	4.00	7.10	1.80	5.60
7	1.90	1.90	1.90	2.40	3.00	1.60	1.90	2.20	3.80	5.00	1.80	4.20
8	1.90	1.80	1.90	2.00	2.60	1.60	2.30	2.00	3.00	3.20	1.70	3.10
9	1.90	1.80	1.90	2.00	2.00	1.60	1.70	1.90	2.10	2.20	1.80	2.60
10	1.90	1.70	1.90	2.00	1.70	1.50	1.70	2.00	1.80	1.90	1.90	1.80
11	1.90	1.70	1.80	2.00	1.70	1.50	1.60	3.00	1.60	1.80	1.80	1.80
12	1.90	1.60	1.80	1.90	1.80	2.00	2.70	4.50	1.60	1.80	1.70	1.80
13	1.90	1.60	2.00	1.90	2.00	2.10	1.80	5.30	1.60	1.90	1.70	1.70
14	1.90	1.60	2.60	1.90	2.80	1.70	1.80	4.30	1.50	1.90	1.80	1.60
15	2.00	1.50	2.90	1.80	1.80	1.80	1.50	3.80	1.50	1.80	1.80	1.60
16	2.00	1.50	2.80	1.80	1.70	1.80	2.40	2.80	1.50	1.80	2.00	1.60
17	2.20	1.50	2.60	1.60	1.60	1.70	2.00	2.20	1.50	1.70	2.80	1.60
18	2.00	1.80	2.30	1.60	1.80	2.10	1.80	2.00	1.60	1.70	1.70	1.80
19	2.00	2.00	2.80	1.70	1.70	2.00	1.80	1.80	1.60	1.70	1.80	2.00
20	3.00	2.10	2.00	1.70	1.70	2.00	2.00	3.50	1.50	2.30	1.70	2.80
21	2.60	2.20	1.90	1.70	1.80	1.90	1.80	5.70	1.50	2.50	1.80	2.00
22	2.60	2.00	1.90	1.90	1.80	1.80	2.10	4.10	1.50	5.05	2.00	2.40
23	2.60	2.10	1.80	2.00	2.95	1.80	2.90	2.70	5.65	5.70	2.30	2.10
24	3.00	1.80	1.80	2.30	5.35	1.70	2.80	2.60	13.40	3.80	2.00	1.90
25	3.90	1.80	1.80	3.10	3.00	1.70	3.00	1.70	14.80	3.80	2.10	2.00
26	4.00	1.80	1.80	2.20	2.80	1.70	2.80	1.80	6.20	2.60	1.90	2.00
27	3.20	1.60	1.90	2.20	2.00	1.60	3.00	2.20	2.20	2.00	1.90	2.00
28	2.80	1.60	2.00	1.90	2.00	1.60	3.00	2.00	1.80	1.90	1.80	1.90
29	2.60	.....	2.10	1.80	1.90	1.80	4.60	1.80	1.80	1.90	1.80	1.80
30	2.60	.....	3.60	1.80	1.70	1.80	3.90	4.95	1.90	1.80	1.80	2.00
31	2.40	.....	6.10	.....	1.70	.....	2.00	4.00	.....	2.00	.....	2.80

Daily gage height, in feet, of Yadkin (Pedee) River at Norwood, North Carolina, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	1.80	1.80	1.50	4.20	1.80	1.70	1.20	1.90	2.40	1.90	1.90	2.10
2	1.80	1.90	1.60	3.40	1.70	1.60	1.20	1.70	2.60	1.70	1.70	2.20
3	1.80	1.70	1.70	2.50	1.60	1.50	1.00	1.80	2.50	1.60	2.10	2.20
4	1.70	1.50	2.30	2.40	1.60	1.30	1.00	1.70	1.90	1.80	2.20	3.10
5	1.50	1.60	2.50	3.00	1.50	1.30	.90	1.60	2.20	1.90	2.30	4.70
6	1.60	1.70	2.40	4.50	1.50	1.30	1.30	1.50	4.10	5.60	2.90	4.50
7	1.70	1.60	2.10	3.40	1.60	1.20	2.00	2.00	3.60	4.60	2.70	3.60
8	1.70	1.60	1.90	2.60	2.30	1.20	1.70	1.70	2.70	2.90	2.50	3.40
9	1.60	1.50	1.80	2.30	2.00	1.30	1.40	1.60	2.60	2.40	2.10	3.90
10	1.50	1.50	1.80	2.20	1.80	1.20	1.40	1.50	2.40	2.30	1.90	2.90
11	1.70	1.60	1.60	2.10	1.60	1.30	1.50	1.60	1.90	2.10	1.80	2.20
12	1.70	1.60	1.60	2.00	1.60	1.30	2.10	1.90	1.70	1.90	1.70	2.10
13	1.60	1.60	1.50	1.80	1.70	1.60	1.70	3.00	1.20	1.80	1.80	1.90
14	1.70	1.70	1.70	1.90	1.80	1.30	1.80	1.50	1.50	1.70	2.10	1.90
15	1.70	1.90	2.50	2.00	1.70	1.40	2.10	3.60	1.50	1.80	2.30	1.80
16	1.60	1.70	2.60	2.20	1.60	1.30	1.10	2.50	1.40	1.90	3.20	1.70
17	1.60	1.70	2.70	2.00	1.50	1.40	2.10	2.00	1.20	1.70	2.70	1.80
18	1.60	1.60	2.00	1.90	1.40	2.30	1.90	2.60	1.50	1.80	2.90	1.90
19	1.50	1.70	1.90	1.80	1.40	1.80	1.30	1.90	1.40	1.90	3.10	2.10
20	1.50	1.80	2.30	1.80	1.50	2.20	1.40	1.70	1.30	2.70	3.20	2.20
21	1.70	1.90	2.20	1.70	1.40	2.10	1.30	4.00	1.30	2.60	2.90	2.30
22	2.60	1.90	1.90	1.70	1.40	1.80	1.20	3.20	1.20	2.90	2.40	2.50
23	2.20	1.80	1.70	1.80	2.80	1.60	1.70	2.20	1.50	5.40	2.30	2.90
24	2.00	1.70	1.80	1.90	4.80	1.50	2.20	2.10	7.00	3.80	2.40	3.90
25	2.30	1.60	1.90	2.30	3.80	1.40	2.90	1.90	11.00	2.70	2.20	3.70
26	3.60	1.60	2.10	3.40	2.60	1.20	2.20	1.30	7.00	2.50	2.30	3.90
27	3.70	1.60	2.00	2.30	2.30	1.10	2.90	1.70	3.70	2.40	2.10	3.70
28	3.00	1.50	1.70	2.10	2.00	1.40	2.00	2.50	2.40	2.30	1.90	2.30
29	2.40	.....	1.80	1.80	1.80	1.40	2.30	3.00	2.20	2.20	1.80	2.10
30	2.10	.....	5.70	1.80	1.60	1.30	3.00	3.40	2.00	2.70	1.90	1.90
31	2.00	.....	6.10	.....	1.80	.....	2.30	2.70	.....	2.50	.....	1.80

Daily gage height, in feet, of Catawba River at Catawba, North Carolina, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	2.00	2.20	1.95	3.30	2.10	1.90	1.80	3.45	2.90	3.70	3.10	2.60
2	2.00	2.10	1.95	3.00	2.10	1.90	1.80	3.40	2.60	3.00	2.95	2.60
3	2.00	2.05	1.90	2.60	2.10	1.80	1.80	3.00	3.30	3.50	2.80	2.60
4	1.95	2.00	1.90	2.40	2.05	1.80	1.80	2.75	5.50	9.70	2.80	4.50
5	1.90	2.00	1.90	3.00	2.25	1.80	2.00	9.65	5.65	11.50	2.28	5.60
6	1.90	2.00	1.90	2.90	2.60	1.80	2.50	4.30	4.35	7.20	2.75	3.90
7	2.00	2.00	1.90	2.60	2.50	1.80	2.35	4.00	4.90	6.10	2.70	3.40
8	2.05	2.00	1.90	2.30	2.35	1.80	2.50	3.50	3.90	5.00	2.65	3.00
9	2.00	2.00	1.90	2.20	2.25	1.75	2.80	3.55	3.60	4.10	2.60	2.90
10	1.95	2.00	1.90	2.15	2.15	1.75	2.35	3.70	3.15	3.80	2.60	2.85
11	1.95	2.00	1.90	2.15	2.05	1.75	2.00	4.60	2.60	3.60	2.60	2.80
12	2.00	2.00	1.90	2.10	2.00	1.75	2.00	6.50	2.40	3.40	2.60	2.70
13	2.00	2.00	1.90	2.10	2.00	1.70	1.85	4.80	2.35	3.20	2.60	2.70
14	2.00	2.00	1.90	2.10	1.95	1.70	4.20	3.50	2.30	3.10	2.70	2.65
15	2.00	2.00	1.90	2.10	1.90	1.90	7.00	3.20	2.30	2.95	2.75	2.50
16	1.95	1.95	1.90	2.40	1.90	2.00	4.10	3.10	2.20	2.80	2.75	2.50
17	1.95	1.95	2.00	2.30	1.90	3.50	4.00	2.90	2.10	2.80	2.80	2.50
18	1.95	1.95	2.10	2.25	1.90	2.80	3.70	2.90	2.10	3.40	3.00	2.50
19	1.95	1.95	2.05	2.20	1.85	2.00	3.10	4.30	2.10	3.20	3.30	2.50
20	2.25	1.95	2.05	2.20	1.85	1.95	2.50	4.30	2.10	3.50	3.20	2.50
21	3.00	2.00	2.00	2.20	1.85	1.95	2.40	4.00	2.05	3.30	3.00	2.90
22	3.00	2.00	2.00	2.20	1.85	1.80	2.40	3.20	2.40	7.45	2.80	3.00
23	2.75	2.00	2.00	2.30	1.85	1.80	3.00	3.00	19.95	6.60	2.95	3.15
24	2.50	1.95	2.00	2.25	3.50	1.80	4.50	2.50	11.60	5.00	3.10	3.25
25	3.00	1.95	1.95	2.20	2.50	1.80	3.90	2.50	5.70	4.10	3.00	3.10
26	5.50	1.95	1.95	2.15	2.20	1.80	3.30	2.60	5.40	3.80	2.85	3.00
27	3.40	1.95	2.90	2.10	2.00	1.80	2.80	2.55	4.90	3.50	2.70	3.00
28	3.00	1.95	3.00	2.10	1.90	1.85	3.40	2.45	4.10	3.30	2.70	2.90
29	2.75	.....	3.50	2.10	1.95	1.80	3.50	5.60	3.40	3.30	2.70	2.85
30	2.40	.....	7.50	2.10	1.95	1.80	3.10	3.30	3.30	3.30	2.65	2.85
31	2.30	.....	5.50	.....	1.95	.....	3.50	3.10	.....	3.20	.....	2.90

Daily gage height, in feet, of Catawba River at Rockhill, South Corolina, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	1.80	2.00	1.50	4.40	1.60	1.40	1.25	1.90	1.90	2.50	2.70	2.70
2	1.70	1.90	1.50	3.10	1.60	1.35	1.20	1.80	(a)	2.30	2.60	2.60
3	1.65	1.80	1.50	2.50	1.50	1.25	1.10	1.80	(a)	2.40	2.50	2.50
4	1.60	1.70	1.75	2.20	1.50	1.20	1.00	2.30	(a)	3.35	2.50	2.60
5	1.60	1.70	2.00	2.50	1.50	1.20	1.00	1.80	(a)	10.00	2.50	3.80
6	1.60	1.70	1.80	3.80	1.50	1.10	1.00	5.60	(a)	10.30	2.50	4.90
7	1.60	1.70	1.60	2.90	1.45	1.10	2.40	3.00	(a)	9.80	3.00	3.65
8	1.60	1.70	1.60	2.40	1.70	1.10	2.00	2.50	(a)	4.80	2.60	3.10
9	1.60	1.70	1.55	2.15	1.60	1.10	1.65	2.40	(a)	3.80	2.55	2.90
10	1.60	1.70	1.55	2.00	1.50	1.10	1.90	2.20	(a)	3.30	2.50	2.80
11	1.60	1.70	1.50	2.00	1.50	1.10	1.90	2.50	(a)	3.20	2.50	2.60
12	1.65	1.70	1.50	1.90	1.50	1.10	1.55	3.00	(a)	2.90	2.60	2.60
13	1.65	1.70	1.50	1.85	1.90	1.00	1.45	1.90	(a)	2.80	2.50	2.60
14	1.70	1.70	1.50	1.85	1.65	1.00	1.50	3.00	(a)	2.80	2.60	2.50
15	1.70	1.65	1.70	1.90	1.50	1.10	1.60	3.00	(a)	2.60	2.70	2.50
16	1.70	1.65	1.70	1.80	1.50	1.10	4.10	2.40	(a)	2.50	2.60	2.40
17	1.65	1.60	1.70	1.70	1.40	3.30	2.90	2.40	(a)	2.40	2.60	2.40
18	1.60	1.60	1.70	1.70	1.40	1.60	2.90	2.20	(a)	2.40	2.70	2.40
19	1.60	1.60	2.90	1.60	1.40	2.30	2.00	2.40	(a)	2.55	6.00	2.30
20	1.60	1.65	2.15	1.60	1.40	2.60	1.80	6.30	(a)	5.00	3.10	2.30
21	1.60	1.70	1.90	1.60	1.30	2.10	1.60	7.51	(a)	3.45	3.05	2.80
22	2.25	1.65	1.75	1.55	1.90	2.60	1.55	5.00	(a)	5.65	2.90	2.80
23	2.80	1.65	1.65	1.50	1.20	1.40	1.50	2.50	(a)	8.40	2.80	3.80
24	2.05	1.60	1.60	1.80	1.30	1.30	2.35	2.25	(a)	4.80	2.90	4.40
25	2.10	1.60	1.70	2.10	2.30	1.20	2.80	2.00	(a)	3.70	3.00	3.70
26	3.15	1.50	1.80	2.10	2.20	1.20	2.50	2.15	3.80	3.35	2.80	3.20
27	4.05	1.50	1.70	1.90	1.90	1.45	2.40	2.30	3.20	3.30	2.70	2.90
28	3.00	1.50	1.60	1.80	1.60	1.20	2.55	2.00	2.90	3.10	2.60	2.80
29	2.50	.....	1.60	1.70	1.55	1.40	2.10	2.00	2.80	2.90	2.50	2.70
30	2.25	.....	3.10	1.60	1.50	1.30	2.90	4.00	2.60	2.70	2.70	2.60
31	2.10	.....	6.60	.....	1.40	.....	2.80	3.60	.....	2.90	.....	2.60

a Gage broken.

Daily gage height, in feet, of Broad River at Gaffney, South Carolina, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	3.49	3.71	3.31	4.69	3.55	3.07	2.72	3.32	3.71	(a)	2.02	2.00
2	3.39	3.62	3.19	4.58	3.42	3.11	2.73	3.11	3.79	(a)	2.01	2.00
3	3.38	3.55	3.29	3.89	3.35	3.13	2.78	3.25	3.81	(a)	2.01	2.00
4	3.31	3.84	3.28	4.85	3.36	3.14	2.66	3.19	4.12	(a)	2.01	2.70
5	3.19	4.64	3.42	4.88	3.34	3.04	2.92	5.39	5.89	(a)	2.01	4.30
6	3.21	4.56	3.08	4.79	3.41	2.98	3.71	3.85	6.96	(a)	2.07	2.70
7	3.12	4.49	3.06	4.19	3.38	2.95	4.81	3.53	4.59	(a)	2.07	2.40
8	3.13	4.61	3.31	3.69	3.45	2.82	3.73	3.28	5.19	(a)	2.06	2.30
9	2.98	3.89	3.32	3.65	3.35	2.71	3.17	3.21	4.11	(a)	2.01	2.30
10	3.15	3.74	3.41	3.58	3.31	2.89	3.14	3.11	3.68	(a)	2.01	2.20
11	3.13	3.68	3.34	3.49	3.34	2.79	3.22	4.28	3.58	(a)	2.00	2.00
12	3.03	3.45	3.32	3.39	3.25	2.69	3.24	3.75	3.65	(a)	2.00	2.00
13	3.05	3.26	3.31	3.35	3.33	2.59	3.44	3.95	3.55	(a)	2.00	2.00
14	3.03	3.04	3.28	3.41	3.36	2.78	3.83	5.79	3.39	(a)	2.02	2.00
15	3.04	3.39	3.42	3.57	3.31	2.71	4.82	4.42	3.45	(a)	2.02	1.90
16	3.21	3.49	3.51	3.54	3.22	2.81	3.95	3.41	3.21	(a)	2.00	1.90
17	3.27	3.41	3.34	3.49	3.31	3.05	3.73	3.38	3.25	(a)	2.02	1.80
18	3.25	3.34	3.48	3.39	3.28	3.02	3.55	3.36	3.22	(a)	2.00	1.70
19	3.31	3.31	3.46	3.55	3.25	3.65	3.19	3.61	3.29	(a)	2.04	1.70
20	3.35	3.24	3.55	3.43	3.21	3.52	3.09	5.45	3.25	(a)	2.30	2.50
21	3.41	3.32	3.48	3.32	3.22	3.21	3.07	3.56	3.21	(a)	2.30	3.00
22	4.84	3.42	3.29	3.29	3.31	3.25	3.02	3.42	3.19	(a)	2.10	2.50
23	3.69	3.35	3.44	3.28	3.32	2.89	3.04	3.68	11.28	(a)	2.20	4.20
24	3.51	3.25	3.32	3.62	3.21	2.96	5.03	3.34	10.65	(a)	2.30	3.50
25	3.83	3.28	3.29	4.11	3.49	2.93	3.98	3.25	6.15	(a)	2.00	3.00
26	4.91	3.26	3.28	3.59	3.29	3.05	3.52	3.28	5.31	2.07	2.00	2.70
27	4.44	3.23	3.22	3.53	3.19	2.98	3.41	3.33	5.01	2.06	2.00	2.50
28	4.24	3.33	3.25	3.85	3.21	2.91	3.25	3.21	4.85	2.04	2.00	2.20
29	4.13	.....	3.32	3.65	3.18	2.84	3.48	3.22	3.93	2.04	2.00	2.20
30	3.72	.....	5.12	3.54	3.15	2.81	3.29	3.51	3.85	2.09	2.10	2.10
31	3.41	.....	5.68	.....	3.05	.....	3.15	3.81	.....	2.07	.....	2.10

a Gage broken.

Daily gage height, in feet, of Broad River at Alston, South Carolina, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	3.01	3.99	3.20	7.21	3.95	2.90	2.63	3.90	5.33	3.92	4.00	4.33
2	3.50	3.80	3.55	6.11	3.79	2.81	2.49	4.61	4.76	3.71	3.99	4.00
3	3.30	3.65	3.30	4.90	3.50	2.71	2.33	5.81	4.39	3.80	3.90	3.70
4	3.19	3.55	4.60	4.31	3.61	2.84	2.31	4.62	4.71	3.14	3.69	4.45
5	3.45	3.50	.....	5.60	3.50	2.45	1.95	3.68	5.01	4.50	3.65	6.85
6	3.30	3.50	4.65	8.63	3.31	2.50	1.78	6.62	7.98	8.20	3.64	6.29
7	3.40	3.49	3.97	7.00	3.32	2.32	3.90	4.22	7.28	6.86	3.99	5.87
8	3.50	3.15	3.50	5.50	3.25	2.42	5.86	4.68	9.18	5.88	3.88	4.92
9	3.30	3.45	3.60	4.58	3.24	2.50	4.85	4.15	6.50	4.79	3.84	4.50
10	3.45	3.47	3.50	4.30	2.78	2.60	4.72	3.80	4.95	4.80	3.60	4.28
11	3.39	3.40	3.35	4.40	3.18	2.28	4.45	3.38	4.01	4.50	3.61	4.12
12	3.39	3.39	3.30	4.10	3.11	2.29	3.15	4.43	3.63	4.00	3.68	4.06
13	3.59	3.33	3.25	4.00	2.92	2.15	3.30	4.70	3.54	3.90	3.80	4.00
14	3.27	3.21	3.12	3.85	3.05	1.85	3.95	5.35	3.60	3.80	4.21	3.98
15	3.30	3.12	3.70	4.09	3.30	2.65	4.83	7.12	3.46	3.92	4.10	3.80
16	3.41	3.31	3.78	4.00	3.00	2.61	5.72	6.50	3.41	3.63	4.50	3.78
17	3.30	3.26	3.72	3.80	2.81	3.20	4.75	5.65	3.39	3.72	4.25	3.69
18	3.02	3.11	3.79	3.60	3.10	4.40	4.80	5.85	3.26	3.00	4.90	3.72
19	3.30	3.15	3.60	3.40	3.31	4.18	4.00	6.87	3.19	3.81	5.08	3.68
20	3.19	3.50	3.91	3.80	2.95	4.55	3.70	9.28	2.79	5.20	5.20	3.59
21	3.70	3.60	3.71	3.57	2.89	4.80	3.12	8.48	2.22	4.10	4.52	4.36
22	4.05	3.41	3.40	3.40	2.83	4.20	3.01	5.85	2.89	6.86	4.31	5.50
23	4.10	3.34	3.50	3.41	2.80	3.55	3.18	4.60	3.20	10.52	4.11	5.82
24	3.75	3.36	3.49	4.57	2.48	3.15	4.25	4.30	14.39	8.21	4.10	7.70
25	4.50	3.30	3.52	5.30	2.80	2.80	7.89	4.08	13.60	5.81	4.20	6.31
26	8.43	3.25	3.43	4.52	3.00	2.89	6.50	3.91	9.14	4.74	3.80	5.47
27	8.51	3.06	3.34	4.73	2.20	2.30	5.23	4.95	5.39	4.60	3.80	4.90
28	6.15	3.14	3.29	5.96	2.60	2.70	5.45	4.01	4.49	4.27	3.68	3.65
29	4.94	.....	3.30	5.15	2.71	2.78	4.80	3.51	4.38	4.07	3.48	3.44
30	4.33	.....	6.80	4.25	2.55	2.80	4.23	7.55	4.02	4.01	4.32	3.32
31	4.00	.....	6.85	.....	2.40	.....	3.77	6.20	.....	4.10	.....	3.25

Daily gage height, in feet, of Saluda River at Waterloo, South Carolina, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	4.63	4.05	3.85	7.55	3.95	3.75	3.20	5.65	5.15	4.80	4.95	4.50
2	3.55	4.80	4.50	5.83	4.00	3.67	3.70	4.45	7.30	4.40	4.50	4.45
3	3.05	3.85	4.90	5.42	3.75	3.48	2.95	5.50	6.70	4.55	4.85	4.60
4	4.50	3.85	5.10	4.00	3.73	3.45	1.90	4.15	8.05	5.95	4.85	7.40
5	4.55	3.85	4.60	7.00	3.70	3.61	2.00	5.55	6.90	7.40	4.80	8.00
6	4.45	3.77	3.65	6.87	4.77	3.00	3.65	6.90	7.50	6.45	5.15	6.20
7	4.55	4.05	3.75	5.90	3.75	4.06	4.20	6.35	7.00	7.85	3.35	5.15
8	4.40	4.60	4.50	4.60	4.00	3.40	6.27	6.15	6.70	6.95	4.95	4.95
9	3.80	4.15	3.95	5.23	3.50	3.90	5.15	4.90	5.70	7.65	4.50	4.70
10	3.05	4.20	3.80	4.45	4.65	3.35	4.75	4.10	5.25	5.65	4.40	4.65
11	4.45	4.60	3.75	4.60	3.85	2.65	4.35	5.75	5.45	5.35	4.20	5.60
12	4.62	3.95	4.55	5.05	3.75	3.25	3.68	5.60	3.70	4.85	4.95	3.90
13	4.35	3.60	3.87	4.35	3.65	2.40	4.70	6.15	4.80	4.65	6.50	4.90
14	4.32	4.00	3.35	4.45	4.75	4.00	5.47	6.80	4.25	4.30	4.10	4.60
15	4.30	4.15	4.35	5.10	4.00	3.35	6.65	9.75	3.80	4.80	5.40	4.50
16	3.65	4.20	4.30	4.90	3.85	3.35	6.20	11.10	3.80	4.35	4.60	3.95
17	3.48	3.95	4.75	5.20	3.85	3.60	5.00	5.95	4.65	4.50	4.80	4.50
18	3.90	4.00	3.95	3.60	4.60	3.15	3.50	5.30	3.65	4.50	5.00	5.00
19	3.90	4.02	4.70	4.40	3.55	4.83	4.35	7.98	4.10	5.25	5.70	4.55
20	4.08	3.70	3.60	4.10	4.40	5.30	3.40	7.50	4.50	5.70	5.40	5.70
21	4.78	3.60	4.00	3.95	4.20	5.85	3.50	7.40	3.75	8.75	4.85	5.10
22	4.70	3.75	4.40	4.00	3.30	5.07	3.75	6.55	3.90	11.35	4.50	5.60
23	4.65	4.55	4.60	4.85	2.60	3.80	4.70	6.05	7.28	10.00	4.60	6.55
24	4.10	4.50	3.75	5.55	4.50	3.60	7.60	5.10	10.95	7.05	5.00	7.65
25	6.60	4.15	4.63	5.20	3.75	4.40	8.30	4.60	12.50	5.75	4.50	7.00
26	8.25	3.95	4.55	4.25	3.50	3.45	6.00	4.35	6.20	5.35	4.40	6.30
27	6.95	3.55	3.60	5.00	4.08	2.60	5.00	6.60	5.45	5.20	5.50	4.70
28	5.67	2.90	2.95	4.75	4.57	3.80	5.00	5.25	4.90	4.85	4.40	5.20
29	5.20	.....	3.95	4.70	3.25	3.60	4.75	4.10	4.90	4.90	4.70	4.80
30	4.50	.....	6.00	4.85	3.15	3.33	4.75	4.95	4.55	5.80	4.60	4.40
31	4.55	.....	7.85	.....	4.15	.....	4.53	4.20	.....	4.70	.....	3.80

Daily gage height, in feet, of Tugalo River at Madison, South Carolina, for 1898.

Day.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Day.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	.....	2.30	6.40	3.00	3.60	5.00	17	.....	4.10	3.70	4.30	3.60	2.70
2	.....	2.10	20.00	2.80	3.50	3.40	18	.....	6.40	3.60	9.35	3.60	2.70
3	.....	6.20	17.00	3.10	3.40	3.40	19	2.10	5.70	3.40	6.20	4.70	2.70
4	.....	9.75	13.00	18.00	3.30	3.50	20	1.90	5.70	3.30	5.00	4.00	4.50
5	.....	9.20	8.20	22.00	3.40	4.30	21	1.80	4.30	3.20	5.50	3.60	3.50
6	.....	6.70	7.30	14.00	4.10	3.60	22	1.70	3.80	3.40	6.30	3.40	3.20
7	.....	5.40	6.30	8.70	3.40	3.50	23	4.10	3.40	8.10	5.20	6.30	7.80
8	.....	6.10	5.40	7.80	3.30	3.40	24	4.40	3.40	4.30	4.70	4.70	4.70
9	.....	4.70	4.90	6.80	3.20	3.30	25	4.50	3.80	3.70	4.50	4.10	4.00
10	.....	4.80	4.90	6.20	3.30	3.20	26	4.00	3.90	3.40	4.30	3.90	3.70
11	.....	8.90	4.80	5.80	4.10	3.60	27	2.90	3.60	3.30	4.20	3.60	3.50
12	.....	7.95	4.50	5.50	3.40	3.00	28	4.10	3.10	3.20	4.10	3.40	3.40
13	.....	6.70	4.20	5.10	3.30	2.90	29	3.00	2.90	3.20	3.90	3.50	3.30
14	.....	7.90	4.10	4.80	4.00	2.90	30	2.80	3.40	3.10	3.90	3.80	3.20
15	.....	4.80	3.90	4.60	3.50	2.80	31	2.30	3.20	.....	3.70	.....	3.30
16	.....	4.50	3.80	4.40	3.40	2.80							

Daily gage height, in feet, of Savannah River at Calhoun Falls, South Carolina, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.
1	2.30	3.25	2.30	4.60	2.65	1.80	1.75	3.20
2	2.30	3.10	2.35	3.40	2.75	1.80	1.70	3.00
3	2.25	3.00	2.45	3.25	2.80	1.80	1.65	3.60
4	2.25	2.90	2.80	3.00	2.80	1.75	1.60	3.00
5	2.20	2.85	3.00	4.45	2.75	1.95	1.90	2.75
6	2.40	2.80	2.80	4.00	2.70	2.05	2.45	2.50
7	2.35	2.75	2.65	3.80	2.60	2.00	2.75	5.05
8	2.30	2.65	2.60	3.55	2.55	1.95	3.95	4.40
9	2.25	2.60	2.50	3.20	2.50	1.85	3.05	a3.25
10	2.25	2.60	2.45	3.00	2.50	1.80	2.60	.....
11	2.20	2.55	2.35	3.15	2.40	1.75	2.45	.....
12	2.20	2.60	2.25	3.05	2.25	1.75	2.30	.....
13	2.15	2.50	2.20	3.00	2.15	1.95	2.50	.....
14	2.15	2.50	2.25	3.00	2.00	1.90	4.90	.....
15	2.20	2.45	2.50	2.90	2.20	1.90	5.05	.....
16	2.40	2.40	2.40	2.70	2.10	1.95	3.95	.....
17	2.35	2.35	2.45	2.65	2.05	2.00	3.60	.....
18	2.35	2.30	2.35	2.55	2.00	2.05	3.40	.....
19	2.45	2.30	2.30	2.50	2.05	2.25	3.25	.....
20	2.85	2.30	2.30	2.65	2.00	2.35	3.00	.....
21	2.70	2.35	2.30	2.50	1.90	2.05	2.85	.....
22	2.65	2.30	2.25	2.45	2.00	2.00	2.50	.....
23	2.90	2.30	2.20	2.35	1.95	1.95	2.75	.....
24	2.85	2.25	2.25	2.75	1.95	1.90	4.00	.....
25	3.65	2.25	2.25	3.00	1.90	1.85	4.50	.....
26	5.50	2.25	2.20	2.85	1.85	1.90	4.05	.....
27	4.65	2.35	2.20	3.05	1.85	1.85	3.85	.....
28	4.05	2.40	2.25	2.90	1.80	1.80	4.00	.....
29	3.85	.....	2.30	2.80	1.80	1.80	3.75	.....
30	3.60	.....	3.90	2.70	1.85	1.80	3.90	.....
31	3.45	.....	6.75	.....	1.80	.....	3.65	.....

a Discontinued.

Daily gage height, in feet, of Savannah River at Augusta, Georgia, for 1896.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	12.0	8.3	10.3	7.8	8.4	5.1	4.7	5.9	4.5	8.7	5.0	14.5
2	10.3	8.2	9.1	7.9	7.3	5.5	4.3	6.2	4.3	6.2	5.8	16.0
3	8.7	9.8	8.3	9.6	7.7	7.7	4.4	7.0	4.2	5.3	5.5	16.8
4	7.9	13.3	7.8	8.8	8.2	8.8	4.3	6.6	4.2	5.0	5.2	14.5
5	7.3	12.0	7.7	7.5	10.6	8.2	9.8	6.4	4.0	4.7	15.2	13.0
6	7.0	19.1	7.5	7.0	9.7	7.5	6.3	6.3	4.9	4.5	20.9	11.2
7	6.7	22.7	7.6	7.1	9.9	6.5	8.8	5.7	11.2	4.3	17.3	10.1
8	6.7	20.5	8.0	6.9	8.2	5.8	22.4	5.2	8.7	4.1	11.0	10.2
9	7.2	24.2	8.0	6.8	7.2	5.7	29.2	4.9	6.1	3.9	8.1	9.8
10	8.0	24.3	7.8	6.7	6.7	5.7	30.2	4.8	5.2	3.8	7.0	9.2
11	7.6	19.5	7.5	6.6	6.3	5.7	25.8	4.8	4.8	4.0	6.6	8.9
12	6.9	14.8	9.6	7.2	6.0	6.4	20.1	5.2	4.7	3.8	6.0	8.4
13	6.7	12.7	10.5	6.5	5.9	6.0	15.0	5.3	4.9	3.8	9.6	7.9
14	6.5	11.2	9.9	6.6	5.8	5.5	11.7	4.9	4.4	3.9	13.4	7.3
15	6.4	12.0	8.0	6.5	5.7	5.0	9.5	6.0	4.2	4.0	10.6	8.3
16	6.5	11.6	7.7	6.5	5.7	4.9	8.6	6.0	4.2	4.7	8.3	17.6
17	10.3	10.4	7.7	6.3	5.6	4.7	8.0	5.8	4.0	4.1	7.2	15.4
18	16.7	9.6	7.8	6.2	5.5	4.6	8.0	5.5	4.2	4.2	6.8	11.8
19	14.5	9.1	7.6	6.3	5.4	4.8	8.0	5.0	4.0	3.9	6.2	9.9
20	11.0	8.8	8.0	6.2	5.2	6.2	8.8	4.9	4.8	3.9	6.0	8.3
21	8.9	8.6	8.2	5.9	5.1	6.1	8.8	4.8	3.9	3.8	6.0	8.0
22	8.3	8.2	8.4	5.8	5.0	5.9	8.8	4.6	3.8	3.7	5.9	7.2
23	9.0	7.9	8.0	5.8	4.9	6.0	8.4	4.5	3.8	3.4	5.7	7.3
24	17.8	8.0	7.7	5.7	5.8	6.9	8.6	4.4	3.9	3.5	5.6	6.9
25	22.2	8.0	7.8	8.8	6.3	5.8	7.8	3.9	5.2	4.8	5.4	6.9
26	18.5	8.0	8.0	7.7	6.6	5.3	7.2	5.2	4.9	5.9	5.3	6.6
27	14.1	7.9	7.7	7.2	5.9	5.0	6.2	4.9	4.8	5.5	5.5	6.1
28	11.3	7.8	7.6	6.9	5.8	4.9	6.0	5.3	4.0	5.0	5.3	6.5
29	9.9	9.2	7.2	6.8	5.7	4.9	6.8	5.7	3.9	4.8	6.3	6.0
30	9.0	.....	7.1	6.8	5.7	4.8	7.0	5.8	10.1	4.4	9.4	5.9
31	8.7	.....	7.1	.....	5.6	.....	6.6	4.9	.....	4.0	.....	5.8

Daily gage height, in feet, of Savannah River at Augusta, Georgia, for 1897.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	6.0	7.2	11.1	11.0	8.9	6.8	8.9	5.8	5.0	4.7	5.0	7.9
2	6.1	10.3	10.0	19.2	16.9	6.8	6.7	5.8	6.1	4.8	4.9	7.4
3	6.0	15.5	9.5	18.0	15.5	6.5	5.9	5.6	6.3	4.8	6.9	6.8
4	6.2	14.2	9.3	17.7	11.2	8.3	6.0	5.4	6.8	4.7	8.0	6.4
5	6.5	11.6	9.5	19.4	9.8	7.5	5.8	5.6	6.8	4.3	6.8	6.9
6	6.4	23.3	9.2	28.5	9.1	8.5	8.2	5.5	5.4	4.2	6.0	7.3
7	6.8	27.1	14.6	27.0	8.8	8.7	9.7	10.4	4.9	4.2	6.2	7.0
8	6.5	25.2	20.1	19.5	8.7	8.4	8.2	10.5	4.8	4.3	4.9	7.3
9	6.2	18.3	15.6	15.5	8.4	9.5	7.3	8.6	4.8	4.1	5.4	6.9
10	6.0	14.4	12.5	15.6	8.2	11.7	7.1	6.8	4.8	4.0	5.0	6.6
11	6.2	12.1	11.1	14.7	8.2	9.3	7.8	6.1	4.8	3.9	5.0	6.4
12	5.9	20.3	11.2	12.8	8.2	8.0	7.3	5.9	4.8	6.6	5.2	6.0
13	5.8	22.8	18.6	11.8	8.3	7.1	8.0	5.8	4.9	7.8	5.0	5.9
14	6.8	19.9	23.9	11.2	9.8	6.9	8.8	5.5	4.6	8.5	5.0	6.0
15	12.4	15.6	25.2	10.8	9.7	6.8	7.0	5.7	4.3	6.9	5.0	6.0
16	11.7	13.0	23.8	10.7	9.0	7.5	6.0	5.3	4.2	6.0	4.9	6.6
17	10.1	14.1	19.3	10.8	8.2	8.5	5.7	10.7	4.4	5.6	4.9	7.5
18	9.2	12.9	17.0	10.2	8.0	8.6	8.2	9.5	4.2	5.3	4.9	6.6
19	13.4	11.1	14.4	10.0	7.8	7.1	9.5	10.8	4.3	5.2	4.9	6.5
20	11.8	10.2	13.8	9.5	7.7	6.9	16.6	16.6	4.8	5.9	4.9	6.2
21	10.2	11.0	16.7	9.4	7.7	6.9	15.5	12.0	4.7	7.7	4.9	6.3
22	20.8	12.5	15.3	9.2	7.4	7.0	14.2	20.3	4.5	8.4	4.9	6.8
23	17.9	11.8	13.6	9.0	7.6	6.5	11.3	16.8	12.2	6.9	4.9	7.0
24	13.4	13.3	14.5	9.1	7.3	6.1	8.8	12.2	12.5	6.1	4.8	7.6
25	10.7	15.0	13.7	9.1	7.2	6.0	7.5	10.6	8.9	5.8	4.9	7.4
26	9.2	20.3	12.1	8.8	7.0	6.1	6.8	8.8	6.6	5.6	5.0	7.0
27	8.8	18.0	10.9	8.8	7.0	6.6	7.0	6.7	5.3	5.3	5.0	7.5
28	8.3	13.6	10.5	8.8	6.8	6.2	10.7	5.9	5.1	5.2	8.6	8.6
29	8.0	.....	9.8	8.5	6.8	5.9	8.7	5.7	5.0	5.0	9.4	8.2
30	7.6	.....	9.3	8.5	6.9	9.3	7.4	5.5	4.9	5.0	8.8	7.7
31	7.0	.....	9.4	.....	6.8	.....	6.0	5.3	.....	5.0	.....	6.9

Daily gage height, in feet, for Savannah River at Augusta, Georgia, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	6.5	7.8	6.0	15.9	8.3	4.5	4.0	8.0	15.3	7.2	8.4	10.0
2	6.3	7.5	5.9	12.5	7.6	4.7	3.8	7.8	28.4	7.1	8.0	9.2
3	6.2	7.1	5.9	9.7	7.3	4.7	4.0	6.9	28.4	7.2	7.9	9.6
4	6.0	6.8	6.2	8.5	7.0	4.5	4.2	6.5	27.8	17.9	7.8	12.7
5	5.9	6.7	10 0	9.0	6.8	4.4	3.7	8.4	27.0	17.8	7.6	16.2
6	6.0	6.5	9.1	17.7	6.5	4.2	3.3	15.5	22.6	24.0	7.5	14.8
7	6.2	6.4	7.6	18.0	6.5	4.6	8.4	12.4	18.2	23.4	8.3	12.4
8	6.3	6.5	6.8	14.0	6.8	4.5	10.6	10.7	15.9	16.7	8.7	10.5
9	5.9	6.3	6.5	10.9	6.0	4.4	12.4	10.4	17.9	13.5	7.8	9.6
10	6.1	6.3	6.0	9.0	6.1	4.4	9.9	9.2	13.7	11.4	7.5	9.0
11	6.0	6.1	6.0	8.5	5.9	4.0	12.3	8.3	11.5	10.7	7.4	8.8
12	6.0	6.2	6.0	8.9	5.9	4.8	8.5	10.0	9.9	9.8	7.8	8.8
13	6.2	6.1	6.0	8.4	5.9	4.4	9.6	11.1	9.0	9.3	8.2	8.5
14	6.3	6.0	6.0	8.0	5.9	4.2	14.0	14.4	8.7	9.0	10.1	8.4
15	6.3	6.0	8.7	8.5	6.7	4.2	16.4	11.8	8.5	8.6	11.0	8.1
16	6.1	5.9	11.8	8.2	6.0	4.4	17.5	13.5	8.2	8.8	10.3	8.0
17	6.1	5.9	9.0	7.9	5.6	4.5	13.9	10.8	8.0	7.8	17.4	7.9
18	6.0	5.9	8.0	7.2	5.5	5.3	9.4	9.6	7.9	7.6	15.5	8.0
19	6.0	6.2	7.6	7.0	5.7	6.1	7.8	11.8	7.1	8.4	14.3	7.9
20	6.0	6.2	7.5	6.9	5.6	8.0	6.9	19.9	7.6	12.0	15.0	8.0
21	6.0	6.5	6.9	7.0	5.8	9.7	6.4	15.0	7.4	9.6	13.1	8.5
22	8.2	6.5	6.5	7.2	5.6	8.4	5.9	11.8	7.3	15.5	10.8	10.8
23	8.8	6.0	6.5	6.8	5.4	7.0	5.7	9.9	7.9	17.2	9.5	10.2
24	7.2	5.9	6.4	9.2	5.2	5.7	9.8	8.7	13.0	13.8	9.4	13.5
25	7.5	5.9	6.0	11.8	5.3	5.0	17.7	7.9	11.8	11.0	10.3	13.3
26	12.4	5.9	5.9	11.2	5.9	5.3	15.5	8.4	9.4	9.6	9.3	11.2
27	16.7	5.8	5.9	9.1	5.7	4.5	13.2	10.5	8.3	9.0	9.0	10.0
28	14.2	5.9	5.8	10.9	5.6	4.3	10.4	14.8	7.9	8.6	8.8	9.3
29	11.0	.....	6.0	11.1	5.5	4.2	10.9	12.6	7.4	8.5	8.5	9.0
30	9.0	.....	5.4	9.8	4.6	4.0	11.3	15.9	7.3	8.2	9.4	8.6
31	8.2	.....	13.5	.....	4.8	.....	9.0	15.7	.....	8.3	.....	8.5

Daily gage height, in feet, of Broad River at Carlton, Georgia, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	2.05	2.25	1.90	3.60	2.20	1.60	1.40	2.10	9.10	2.15	2.35	2.75
2	2.00	2.15	1.90	2.75	2.15	1.60	1.35	1.95	18.85	2.10	2.35	2.55
3	1.95	2.10	1.95	2.45	2.05	1.60	1.35	1.80	18.53	3.20	2.30	2.80
4	1.95	2.05	2.10	2.30	2.05	1.60	1.40	3.00	13.38	4.85	2.30	3.90
5	1.95	2.00	2.15	5.25	2.00	1.55	1.80	3.85	7.88	11.20	2.30	3.30
6	1.95	2.05	2.05	4.45	2.00	1.50	2.35	4.00	5.00	10.10	3.20	3.10
7	1.95	2.05	2.00	3.00	2.00	1.45	3.50	4.20	4.60	4.35	2.40	2.85
8	1.95	2.00	1.95	2.60	1.95	1.45	2.60	3.40	4.50	3.25	2.35	2.70
9	1.95	2.00	1.90	2.45	1.95	1.40	2.30	2.50	3.50	2.90	2.35	2.60
10	1.90	2.00	1.90	2.40	1.90	1.35	1.95	2.20	2.90	2.70	2.65	2.55
11	1.90	2.00	1.85	2.45	1.90	1.35	1.70	3.05	2.85	2.60	2.45	2.55
12	1.90	2.00	1.85	2.35	1.90	1.40	1.60	6.20	2.70	2.50	2.40	2.50
13	1.90	1.95	1.85	2.25	1.85	2.00	1.90	4.05	2.55	2.45	2.45	2.50
14	1.90	1.95	2.35	2.30	1.85	1.60	4.20	3.50	2.45	2.40	2.95	2.45
15	1.90	1.95	2.80	2.30	1.85	1.50	3.85	3.00	2.40	2.30	2.90	2.40
16	1.90	1.90	2.40	2.25	1.80	1.50	3.55	2.70	2.35	2.25	2.75	2.40
17	1.85	1.90	2.45	2.15	1.80	1.50	2.55	2.35	2.35	2.25	3.00	2.45
18	1.85	1.95	2.35	2.10	1.80	2.40	2.00	3.25	2.25	2.70	3.00	2.45
19	1.85	2.05	2.25	2.05	1.85	2.35	1.80	6.95	2.25	3.35	3.55	2.45
20	2.15	2.00	2.10	2.10	2.10	2.15	1.80	3.60	2.20	2.65	3.40	2.70
21	2.55	2.00	2.05	2.05	1.85	1.80	1.70	3.00	2.20	3.60	2.90	3.00
22	2.35	1.95	2.00	2.00	1.80	1.60	1.65	2.85	2.25	4.45	2.70	3.65
23	2.20	1.95	1.95	2.00	1.80	1.55	9.00	2.55	2.40	3.85	2.70	4.05
24	2.90	1.90	1.95	2.95	1.95	1.55	6.00	2.25	3.45	3.00	2.60	4.85
25	4.90	1.90	1.90	2.75	2.10	1.50	4.20	2.10	2.55	2.65	2.55	3.65
26	5.10	1.85	1.90	2.30	1.80	1.50	3.10	2.45	2.35	2.55	2.50	3.10
27	3.30	1.90	1.90	2.60	1.75	2.30	2.60	2.60	2.25	2.45	2.45	2.80
28	3.05	1.95	1.85	3.30	1.65	1.55	6.40	3.00	2.20	2.40	2.40	2.70
29	2.70	.....	1.95	2.60	1.60	1.50	4.60	2.70	2.20	2.40	2.75	2.65
30	2.50	.....	3.35	2.35	1.60	1.45	2.70	2.50	2.15	2.45	3.00	2.60
31	2.35	.....	4.40	.....	1.60	.....	2.35	2.35	.....	2.40	.....	2.65

Daily gage height, in feet, of Oconee River at Cary, Georgia, for 1898. (a)

Day.	Jan.	Feb.	Mar.	Day.	Jan.	Feb.	Mar.	Day.	Jan.	Feb.	Mar.
1	2.20	2.70	2.30	12	2.30	2.30	2.30	23	2.40	2.20	2.40
2	2.10	2.50	2.20	13	2.20	2.30	2.20	24	2.40	2.20	2.40
3	2.00	2.40	2.20	14	2.20	2.30	2.60	25	2.50	2.20	2.30
4	2.00	2.40	2.50	15	2.10	2.30	3.50	26	5.00	2.10	2.20
5	2.10	2.50	2.80	16	2.10	2.30	3.90	27	5.70	2.10	2.20
6	2.10	2.40	2.70	17	2.10	2.30	3.50	28	4.50	2.10	2.30
7	2.10	2.40	2.40	18	2.10	2.30	3.90	29	3.50	.....	2.30
8	2.10	2.40	2.40	19	2.00	2.30	3.10	30	3.00	.....	2.30
9	2.00	2.40	2.40	20	2.00	2.30	2.60	31	2.80	.....	2.50
10	2.10	2.40	2.30	21	2.70	2.30	2.40				
11	2.20	2.40	2.30	22	2.70	2.30	2.50				

a Discontinued March 31.

Daily gage height, in feet, of Oconee River at Dublin, Georgia, for 1898.

Day.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	.....	0.50	1.00	4.00	−0.60	−1.00	5.80	11.80	0.80	3.60	5.50
2	.....	.50	2.00	2.60	− .70	−1.10	4.30	13.00	.70	3.30	5.50
3	.....	.50	2.80	1.90	− .70	−1.20	2.80	16.00	2.30	3.10	5.40
4	.....	.90	2.00	1.70	− .80	−1.20	2.00	23.00	6.90	2.60	7.50
5	.....	1.90	2.50	1.40	− .90	−1.30	1.60	24.60	8.70	2.30	8.50
6	.....	3.90	6.00	1.10	−1.00	−1.20	2.00	23.30	9.40	2.10	9.60
7	.....	3.90	7.80	1.00	− .10	− .90	4.20	21.20	10.50	2.00	11.10
8	.....	2.60	8.50	.90	− .10	+ .30	5.90	19.50	11.30	2.00	12.60
9	.....	2.00	9.40	.80	−1.10	1.00	6.40	18.00	13.50	1.80	12.60
10	.....	1.80	10.00	.70	−1.10	1.80	6.50	17.00	15.50	1.70	10.70
11	0.90	1.50	9.80	.60	−1.20	1.80	4.20	16.00	16.00	1.70	7.70
12	.90	1.40	6.50	.60	−1.20	2.80	3.40	14.80	14.50	1.60	6.70
13	.90	1.00	5.90	.80	−1.20	3.00	3.00	12.50	11.80	1.60	6.00
14	.90	.90	3.30	.20	−1.20	1.60	4.80	7.60	5.00	3.90	5.60
15	.90	.90	2.90	.10	− .70	2.90	5.50	4.70	3.90	6.70	5.20
16	.80	2.00	2.50	.00	− .60	4.60	6.50	3.60	3.50	7.20	4.60
17	.80	3.50	2.00	.00	− .40	4.00	6.40	3.00	3.20	7.60	4.20
18	.90	3.50	1.80	− .20	.00	3.20	4.60	3.00	3.00	8.90	4.60
19	1.00	2.80	1.70	− .20	+ .90	1.80	5.90	2.70	3.00	11.00	3.90
20	1.50	3.10	1.50	− .30	.80	.90	6.00	2.30	2.80	13.00	4.00
21	1.50	2.40	1.40	− .30	.60	.50	5.90	2.20	4.30	14.30	4.40
22	1.40	1.90	1.40	− .40	.80	.00	5.00	2.00	5.60	15.00	5.00
23	1.10	1.50	1.30	− .40	.70	− .20	3.60	2.00	6.90	14.10	6.10
24	.90	1.10	1.80	− .40	− .30	+ .10	2.50	1.80	7.50	12.80	6.50
25	.80	1.00	3.90	− .10	− .50	2.60	1.90	2.00	7.80	10.20	6.90
26	.70	1.00	5.50	+ .20	− .70	5.10	1.60	2.80	6.30	8.30	6.70
27	.50	.90	6.00	.80	− .80	6.10	1.90	2.40	4.30	6.20	6.40
28	.50	.80	4.70	.60	− .90	7.00	7.00	1.50	3.50	5.20	5.60
29	.....	.70	4.90	− .10	− .90	6.70	10.50	1.20	3.10	5.00	5.20
30	.....	.60	5.40	− .30	− .90	6.00	10.90	.90	3.00	5.20	4.90
31	.....	.60	.....	− .50	.....	5.60	11.10	.....	3.30	.....	4.00

Daily gage height, in feet, of Ocmulgee River at Macon, Georgia, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	0.50	1.10	0.25	1.75	1.87	−0.53	−0.82	5.11	4.96	0.75	2.54	4.15
2	.45	1.01	.30	.50	1.10	− .48	− .87	3.70	14.48	.72	2.19	3.51
3	.38	1.00	.30	.48	.92	− .52	− .35	2.11	16.60	7.72	2.08	9.40
4	.32	.70	1.08	.60	.78	− .58	− .50	1.85	18.22	16.85	2.00	13.60
5	.32	.69	3.35	4.33	.60	− .70	− .78	10.50	15.76	17.32	1.85	9.72
6	.38	.71	3.30	12.10	.50	− .78	− .90	10.76	14.72	15.15	1.92	8.10
7	.45	.77	1.45	10.13	.58	− .82	+2.12	10.79	11.00	13.35	2.90	6.61
8	.43	.75	1.35	7.90	.58	− .87	1.35	8.72	9.40	11.75	2.03	6.03
9	.41	.67	1.10	4.37	.47	− .80	1.93	4.91	6.90	9.21	1.90	5.21
10	.43	.60	.80	3.92	.30	− .83	3.48	2.70	6.11	7.35	1.83	5.80
11	.58	.60	.75	2.90	.21	− .94	3.62	6.31	4.00	5.02	2.91	4.21
12	.75	.52	.60	2.74	.18	− .95	1.22	12.70	3.65	4.10	3.37	3.64
13	1.63	.50	.60	2.10	.20	− .96	.90	13.00	3.80	3.50	4.22	3.60
14	1.80	.48	.60	1.75	.18	+ .10	1.20	12.97	2.80	3.07	6.41	3.42
15	.90	.36	2.00	1.60	.10	.53	3.20	9.12	2.50	2.85	6.23	3.21
16	.94	.32	3.92	1.50	.04	− .10	3.80	6.52	1.93	2.56	14.10	2.91
17	.83	.25	3.00	1.20	− .08	− .10	2.67	4.92	1.89	2.30	10.21	2.80
18	.76	.40	2.02	.98	− .15	− .38	1.60	5.41	1.72	4.12	9.27	2.77
19	.60	.63	1.49	.85	− .20	+ .11	.70	2.70	1.56	4.38	12.31	3.11
20	.66	.72	1.22	1.02	− .10	.83	.20	4.10	1.30	4.18	9.02	3.00
21	1.45	.64	.95	1.60	− .15	.60	− .11	2.10	1.22	5.21	6.95	4.10
22	1.85	.50	.85	1.32	+ .05	2.21	− .28	1.94	1.48	6.90	5.50	5.67
23	1.56	.40	.75	1.30	.11	.20	− .32	1.90	1.42	5.28	5.15	5.60
24	1.10	.33	.50	7.95	.91	− .41	+3.32	1.42	1.35	4.17	4.31	5.52
25	1.22	.29	.50	8.90	1.52	− .50	2.51	.90	1.31	3.94	4.00	4.91
26	2.70	.25	.45	6.12	1.46	− .53	5.35	.50	1.28	3.20	3.50	4.60
27	5.37	.23	.39	3.15	1.10	+ .30	5.30	4.25	1.12	2.91	3.18	4.07
28	4.31	.22	.36	2.90	.32	.51	3.10	7.21	.98	2.43	2.92	3.80
29	2.50	.....	.39	2.55	− .11	− .42	3.14	9.45	.83	2.32	3.50	3.30
30	2.06	.....	.50	2.05	− .30	− .65	4.30	7.53	.77	2.90	3.31	3.21
31	1.62	.....	1.50	.....	− .36	.....	9.02	5.08	.....	2.71	.....	3.10

List of discharge measurements.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
1898.				*Feet.*	*Sec.-feet.*
Feb. 26	Roanoke River	Roanoke, Va	D. C. Humphreys	0.94	132
May 7	do	do	do	3.75	3,445
July 20	do	do	do	.95	113
Jan. 8	Dan River	Clarksville, Va	E. W. Myers	1.05	2,009
Feb. 26	Staunton River	do	do	.70	1,989
Jan. 11	Roanoke River	Neal, N. C	do	4.43	4,334
May 10	do	do	do	22.50	27,890
Jan. 13	Tar River	Tarboro, N. C	do	2.30	1,823
May 10	do	do	do	7.30	3,757
Jan. 9	Neuse River	Selma, N. C	do	1.20	426
Aug. 31	do	do	do	6.85	2,903
May 6	Haw River	Moncure, N. C	do	1.56	495
Aug. 19	do	do	do	15.40	7,925
May 6	Deep River	do	do	2.00	403
Aug. 20	do	do	do	17.20	14,994
Jan. 10	Cape Fear River	Fayetteville, N. C	do	3.55	1,308
Aug. 22	do	do	do	28.35	23,215
Jan. 17	Yadkin River	Salisbury, N. C	do	2.10	2,567
April 1	do	do	do	3.90	9,110
Aug. 13	do	do	do	5.05	11,237
Jan. 16	Yadkin (Pedee) River.	Norwood, N. C	do	1.63	3,041
Mar. 31	do	do	do	5.75	24,825
Jan. 14	Catawba River	Catawba, N. C	do	2.01	1,228
Jan. 25	do	Rockhill, S. C	do	3.20	7,732
Oct. 26	do	do	do	3.50	7,108
Jan. 26	Broad River	Gaffney, S. C	do	2.67	3,052
Oct. 27	do	Alston, S. C	do	4.60	5,687
Jan. 23	Saluda River	Waterloo, S. C	do	4.65	1,350
Oct. 27	do	do	do	5.10	1,684
May 25	Tugalo River	Madison, S. C	Max Hall	1.50	902
June 9	do	do	do	.90	563
July 19	do	do	do	2.05	1,100
Oct. 28	do	do	do	4.00	2,439
Apr. 16	Savannah River	Calhoun Falls, S. C	do	2.75	4,081
1896.					
Oct. 3	do	Augusta, Ga	B. M. Hall	5.41	3,154
1897.					
July 15	do	do	do	6.67	4,198
Sept. 29	do	do	do	5.17	3,180
Nov. 6	do	do	Max Hall	6.20	4,311
1898.					
Apr. 28	do	do	do	11.55	14,494
June 16	do	do	B. M. Hall	5.25	3,398
July 27	do	do	do	9.85	11,380
July 28	do	do	do	10.37	14,280
Aug. 2	do	do	Knox T. Thomas	7.17	6,302
Aug. 3	do	do	do	6.72	5,511
Sept. 3	do	do	B. M. Hall	28.27	87,472
Sept. 16	do	do	Warren Hall	8.10	7,432
Sept. 17	do	do	do	8.00	7,108
Nov. 14	do	do	Jas. C. Conn	11.66	13,243
Jan. 29	Broad River	Carlton, Ga	Max Hall	2.68	995
Feb. 21	do	do	do	2.00	577
Apr. 20	do	do	do	2.10	667
June 14	do	do	do	1.56	366
July 25	do	do	do	3.75	2,165
Sept. 13	do	do	B. M. Hall	2.50	930
Oct. 8	do	do	do	3.05	1,446
Mar. 22	Oconee River	Cary, Ga	Max Hall	2.50	1,168
Nov. 15	do	do	Jas. C. Conn	3.65	2,396
Feb. 11	do	Dublin, Ga	Max Hall	.95	2,057
Mar. 29	do	do	do	.65	1,927
May 20	do	do	do	—.23	1,272
June 24	do	do	do	—.28	1,164
July 27	do	do	do	6.23	7,007
Aug. 30	do	do	do	10.80	12,161
Oct. 20	do	do	B. M. Hall	3.70	4,153
Jan. 7	Ocmulgee River	Macon, Ga	Max Hall	.42	899
Feb. 10	do	do	do	.60	1,010
Mar. 28	do	do	do	.36	976
Mar. 30	do	do	do	.50	1,028
May 19	do	do	do	—.20	687
June 23	do	do	do	—.34	620
July 26	do	do	do	4.92	3,218
July 27	do	do	do	5.65	3,799
Aug. 29	do	do	do	9.25	6,125
Aug. 30	do	do	do	7.20	4,477
Oct. 19	do	do	B. M. Hall	4.50	3,111
Nov. 5	do	do	Jas. C. Conn	1.90	1,474

List of miscellaneous discharge measurements, 1898.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
				Feet.	*Sec.-feet.*
Jan. 12	Amicalola River	Heards Mill, Hollensheds Bridge, Ga.	Max Hall	1.40	273
Jan. 13	Ellijay River	Ellijay, Ga.	do	1.00	262
Do.	Cartecay River	do	do	1.20	428
Feb. 12	East Long Swamp Creek.	Marble Hill, Ga.	B. M. Hall		20
Apr. 19	Chattahoochee River.	Near Gainesville, Shallow Ford Bridge, Ga.	do	1.20	844
May 26	Choccolocco Creek.	Eureka, Alabama.	do	1.08	171
May 28	Peachtree Creek	At mouth, from first wagon bridge, Oakdale, Ga.	do	*a* .30	36
Do.	Proctor Creek	Mouth, one-fourth mile below Oakdale, Ga.	do	*a* .30	7
June 16	Hiwassee River	Reliance, Tenn	Max Hall	2.84	954
June 23	Long Swamp Creek	Revis Bridge, in Cherokee County, Ga.	B. M. Hall		50
June 25	Amicalola River	Hills Ford, Dawson County, Ga.	do		112
Do.	Talking Rock Creek.	Near Carters, Ga.	Olin P. Hall	*a* 1.12	55
July 7	Peachtree Creek	At mouth, first wagon bridge.	Warren Hall	*a* 1.15	31
Do.	do	do	do	*a* 1.10	33
Aug. 19	Vickerys Creek	Near Roswell, Ga.	B. M. Hall	2.00	129
Aug. 25	Talking Rock Creek.	Carters, Ga	Max Hall	*a* 1.70	79
Dec. 20	Silver Spring	Near Ocala, Fla.	do		822
Dec. 21	Kissingen Spring	Bartow, Fla.	do		31
Dec. 22	Blue Spring	Juliet, Fla.	do		778
Dec. 23	Itchatucknee Spring.	Near Fort White, Fla.	do		408
Oct. 25	Broad River	Blacksburg, S. C.	E. W. Myers	2.90	2,999

a At river station.

Rating tables.

Neal.		Fayetteville.		Catawba.		Rockhill.		Alston.	
Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Sec.-feet.*	*Feet.*	*Sec.-feet.*	*Feet.*	*Sec.-feet.*	*Feet.*	*Sec.-feet.*	*Feet.*	*Sec.-feet.*
0.0	1,750	1.0	489	1.5	750	1.0	1,800	1.0	1,560
.5	1,900	2.0	810	2.0	1,425	1.5	2,610	1.5	1,700
1.0	2,060	3.0	1,187	2.5	2,175	2.0	3,700	2.0	1,900
1.5	2,225	4.0	1,674	3.0	3,050	2.5	5,000	2.5	2,250
2.0	2,410	5.0	2,210	3.5	4,135	3.0	6,350	3.0	2,850
2.5	2,585	6.0	2,740	4.0	5,400	3.5	7,800	3.5	3,620
3.0	2,775	7.0	3,280	4.5	6,780	4.0	9,300	4.0	4,490
3.5	2,975	8.0	3,822	5.0	8,225	4.5	10,800	4.5	5,490
4.0	3,200	9.0	4,382	5.5	9,700	5.0	12,400	5.0	6,490
4.5	3,430	10.0	4,955	6.0	11,175	5.5	14,200	5.5	7,490
5.0	3,660	11.0	5,535	6.5	12,650	6.0	16,000	6.0	8,530
5.5	3,910	12.0	6,133	7.0	14,125	6.5	18,000	6.5	9,590
6.0	4,185	13.0	6,733	7.5	15,600	7.0	20,000	7.0	10,700
6.5	4,460	14.0	7,333	8.0	17,075	7.5	22,500	7.5	11,850
7.0	4,750	15.0	7,933	8.5	18,550	8.0	25,000	8.0	13,000
8.0	5,450	16.0	8,541	9.0	20,025	8.5	27,500	8.5	14,150
9.0	6,250	17.0	9,161	9.5	21,500	9.0	30,000	9.0	15,300
10.0	7,200	18.0	9,781	10.0	22,975	9.5	32,500	9.5	16,450
11.0	8,200	19.0	10,401	10.5	24,450	10.0	35,000	10.0	17,600
12.0	9,300	20.0	11,569	11.0	25,925	10.5	37,500	11.0	20,000
13.0	10,600	21.0	12,928	12.0	28,875	11.0	40,000	12.0	22,500
14.0	12,000	22.0	14,287	13.0	31,825	11.5	42,750	13.0	25,000
15.0	13,500	23.0	15,646	14.0	34,775	12.0	45,500	14.0	27,500
16.0	15,075	24.0	17,005	15.0	37,725	12.5	49,550	15.0	30,000
17.0	16,700	25.0	18,364	16.0	40,675	13.0	53,600	16.0	32,500
18.0	18,400	26.0	19,723	17.0	43,650	13.5	57,700	17.0	35,000
20.0	22,400	27.0	21,082	18.0	46,650	14.0	61,800	18.0	37,500
22.0	27,850	28.0	22,441	19.0	49,650	14.5	65,900	19.0	40,000
24.0	34,650	29.0	23,800	20.0	52,650	15.0	70,000	20.0	42,500
26.0	64,300	30.0	25,159	21.0	55,650	15.5	74,100	22.0	47,500

Rating tables—Continued.

Waterloo.		Madison.		Calhoun Falls.		Augusta.	
Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Sec.-feet.*	*Feet.*	*Sec.-feet.*	*Feet.*	*Sec.-feet.*	*Feet.*	*Sec.-feet.*
1.9	290	0.9	568	1.7	1,450	3.0	2,000
2.0	300	1.0	615	1.8	1,580	3.5	2,150
2.1	310	1.2	715	1.9	1,720	4.0	2,350
2.2	320	1.4	815	2.0	1,875	5.0	3,100
2.3	335	1.6	920	2.1	2,045	6.0	4,020
2.4	350	1.8	1,030	2.2	2,235	7.0	5,400
2.5	375	2.0	1,140	2.3	2,445	8.0	7,200
2.6	400	2.2	1,260	2.4	2,680	9.0	9,340
2.7	430	2.4	1,380	2.5	2,940	10.0	11,800
2.8	465	2.6	1,500	2.6	3,240	11.0	14,620
2.9	505	2.8	1,620	2.7	3,590	12.0	17,750
3.0	550	3.0	1,740	2.8	4,000	13.0	21,100
3.2	630	3.2	1,874	2.9	4,500	14.0	25,000
3.4	715	3.4	2,008	3.0	5,000	15.0	29,300
3.6	805	3.6	2,148	3.1	5,500	16.0	33,600
3.8	900	3.8	2,294	3.2	6,000	17.0	38,000
4.0	1,000	4.0	2,440	3.3	6,500	18.0	42,400
4.2	1,105	4.2	2,598	3.4	7,000	19.0	46,800
4.4	1,215	4.4	2,756	3.5	7,500	20.0	51,200
4.6	1,330	4.6	2,914	3.6	8,000	21.0	55,600
4.8	1,450	4.8	3,072	3.7	8,500	22.0	60,000
5.0	1,575	5.0	3,230	3.8	9,000	23.0	64,400
5.2	1,705	5.5	3,625	3.9	9,500	24.0	68,800
5.4	1,840	6.0	4,020	4.0	10,000	25.0	73,200
5.6	1,980	6.5	4,415	4.2	11,000	26.0	77,600
5.8	2,130	7.0	4,810	4.4	12,000	27.0	82,000
6.0	2,280	7.5	5,205	4.6	13,000	28.0	86,400
7.0	3,080	8.0	5,600	4.8	14,000	.....	.....
8.0	3,930	.....	.....	5.0	15,000	.....	.....
9.0	4,780	.....	.....	.....	.....	.....	.....

Carlton.		Cary.		Dublin		Macon.	
Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Sec.-feet.*	*Feet.*	*Sec.-feet.*	*Feet.*	*Sec.-feet.*	*Feet.*	*Sec.-feet.*
1.4	320	0.0	240	—1.2	890	—1.0	370
1.6	385	.2	260	—1.0	950	— .5	545
1.8	480	.4	290	— .5	1,140	.0	740
2.0	577	.6	320	.0	1,425	.5	940
2.2	700	.8	350	.5	1,746	1.0	1,150
2.4	850	1.0	380	1.0	2,080	1.5	1,380
2.6	1,030	1.2	415	1.5	2,429	2.0	1,630
2.8	1,215	1.4	470	2.0	2,790	2.5	1,905
3.0	1,405	1.6	560	2.5	3,166	3.0	2,180
3.5	1,894	1.8	675	3.0	3,560	3.5	2,455
4.0	2,384	2.0	815	3.5	3,980	4.0	2,730
4.5	2,874	2.2	970	4.0	4,460	4.5	3,005
5.0	3,364	2.4	1,144	4.5	4,998	5.0	3,280
5.5	3,854	2.6	1,320	5.0	5,580	5.5	3,555
6.0	4,344	2.8	1,496	5.5	6,130	6.0	3,830
6.5	4,834	3.0	1,672	6.0	6,700	6.5	4,110
7.0	5,324	3.2	1,848	6.5	7,270	7.0	4,410
7.5	5,814	3.4	2,024	7.0	7,840	7.5	4,715
8.0	6,304	3.6	2,200	7.5	8,410	8.0	5,060
8.5	6,794	3.8	2,376	8.0	8,980	8.5	5,440
9.0	7,284	4.0	2,554	8.5	9,550	9.0	5,880
9.5	7,774	4.2	2,750	9.0	10,120	10.0	6,900
10.0	8,264	4.4	2,965	9.5	10,690	11.0	8,800
10.5	8,754	4.6	3,200	10.0	11,280	12.0	11,800
.....	.....	4.8	3,450	11.0	12,400	13.0	15,000
.....	.....	5.0	3,750	12.0	13,540	14.0	18,200
.....	.....	5.2	4,080	13.0	14,680	15.0	21,400
.....	.....	5.4	4,500	14.0	15,820	16.0	24,600
.....	.....	5.6	4,950	15.0	16,960	17.0	27,800
.....	.....	5.8	5,410	16.0	18,100	18.0	31,000

EASTERN GULF DRAINAGE.

DESCRIPTION OF RIVER STATIONS.

Molina station on Flint River.—Described on page 45 of Paper No. 15. Results for 1897 shown on pages 233–234 of the Nineteenth Annual Report, Part IV. The alternate accumulation and washing out of sediment in an eddy half a mile below so affected the gage heights that it has not been possible to establish a definite relation between them and the discharge measurements of 1897 and 1898. Prof. B. M. Hall has constructed a rating table by averaging the conflicting measurements that were made at or near the same gage heights. This is the best that can be done with the data in hand. A new station will be established as soon as a proper section can be found.

Albany station on Flint River.—This station is maintained by the United States Weather Bureau. The drainage area is approximately 5,000 square miles. The observer is John E. Clark. No discharge measurements were made during 1898. Mr. J. B. Marbury, the local forecast official at Atlanta, Georgia, furnishes the following information: The river gage is in two sections. The long section, from 10 to 36 feet, is nailed in two segments to the south face, downstream side of the west pier on the right or Albany side of river. The short section is nailed to a cypress tree 120 feet down the river from pier. The top of the pier-foundation sill is 8.1 feet above low water. A second gage, reading from zero to 21 feet, is nailed to a cypress tree on left-hand bank of river, about 100 feet downstream from the point where the south side of Commerce street, if extended, would cross the river. The first bench mark is the top of the white marble foundation stone of the A. M. E. Church, corner of Washington and State street, Albany, Georgia. It is 49.5 feet above zero of gage. The second bench mark is the top of the sill of the old wharf at the foot of Broad street. It is 3 feet above low water.

Oakdale station on Chattahoochee River.—Described on page 46 of Paper No. 15. Results for 1897 shown on page 235 of the Nineteenth Annual Report, Part IV. On July 1 the station was moved to Mason and Turner's Ferry, 1 mile below Oakdale. The observer is C. H. Turner. The gage at this point, known as Oakdale lower gage, is nailed to a tree on the right bank, 100 yards below the ferry, and is set 1 foot deeper in the water than the gage at the Southern Railroad Bridge.

West Point station on Chattahoochee River.—Described on page 47 of Paper No. 15. Results for 1897 are shown on page 237 of the Nineteenth Annual Report, Part IV.

Canton station on Etowah River.—Described on page 48 of Paper No. 15. Results for 1897 shown on page 242 of the Nineteenth Annual

Report, Part IV. The zero of gage is 881.02 feet above sea level, as given in Report of United States Weather Bureau, Daily River Stages on the principal rivers of the United States, Part IV, 1893.

Carters station on Coosawattee River.—Described on page 49 of Paper No. 15; results for 1897 shown on page 243 of the Nineteenth Annual Report, Part IV. The observer for 1898 was H. S. Weems.

Resaca station on Oostanaula River.—Described on page 50 of Paper No. 15; results for 1897 given on page 245 of the Nineteenth Annual Report, Part IV.

Rome station on Coosa River.—Coosa River is formed by the junction of Etowah and Oostanaula rivers at Rome, Georgia. Measurements of discharge are made on each of these tributaries. The Etowah River is measured at Second Avenue Bridge and Oostanaula River at Fifth Avenue Bridge, and the results added to give the flow of Coosa River, the junction being a short distance below these bridges. The gage height is taken from the Weather Bureau gage at Fifth Avenue Bridge, on the Oostanaula. There is practically no fall on the Oostanaula River from Fifth Avenue Bridge to the junction, hence the gage is used as Coosa River gage, and gives the fluctuations of Coosa River. This gage is 4 by 6 timber, graduated to feet and tenths, and fastened to the downstream left-hand corner of the first pier from left bank. The zero of gage is 575.79 above sea level. The United States Weather Bureau has maintained a station here for many years. It is now maintained only as a half-year station, from November 1 to April 30, inclusive, but W. M. Towers, the river observer, feels so much personal interest in the matter that he reads the gage during the other six months without compensation, and kindly furnishes the Survey with monthly reports of the daily gage heights for the entire year without charge. Mr. Towers has kept the record for many years, and has predicted floods with great precision.

Riverside station on Coosa River, including locks Nos. 4 and 5.—Described on page 51 of Paper No. 15; results for 1897 given on page 246 of the Nineteenth Annual Report, Part IV.

Wetumpka station on Coosa River.—Described on page 54 of Paper No. 15, and on page 241 of the Nineteenth Annual Report, Part IV.

Milstead station on Tallapoosa River.—Described on page 56 of Paper No. 15; results for 1897 shown on page 249 of the Nineteenth Annual Report, Part IV. This station was established by B. M. Hall August 7, 1897.

Tuscaloosa station on Black Warrior River.—Described on page 57 of Paper No. 15; results for 1897 shown on page 250 of the Nineteenth Annual Report, Part IV. The observer since April 16, 1898, has been R. C. McCalla, jr., United States assistant engineer.

TABLES OF DAILY GAGE HEIGHT.

Daily gage height, in feet, of Flint River at Molina, Georgia, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	Day.	Jan.	Feb.	Mar.	Apr.	May.	June.
1	1.95	2.10	1.80	2.25	1.85	1.05	17	2.10	1.80	2.55	1.85	1.20	.....
2	1.90	2.00	1.80	2.10	1.75	a1.10	18	2.05	1.90	2.40	1.75	1.20	.....
3	1.80	2.00	1.85	1.95	1.65	.....	19	1.95	2.05	2.25	1.70	1.15	.....
4	1.75	1.90	2.40	1.85	1.60	.....	20	2.00	2.05	2.10	1.80	1.20	.....
5	1.85	1.90	2.80	4.00	1.50	.....	21	2.10	2.00	2.00	1.90	1.15	.....
6	1.85	1.90	2.60	5.50	1.45	.....	22	2.30	1.95	1.95	1.90	1.15	.....
7	1.90	1.90	2.40	4.10	1.45	.....	23	2.30	1.90	1.90	1.80	1.15	.....
8	1.95	1.90	2.20	3.50	1.40	.....	24	2.20	1.85	1.80	3.80	1.45	.....
9	2.05	1.90	2.10	2.90	1.40	.....	25	2.10	1.85	1.80	3.85	1.80	.....
10	2.00	1.95	2.00	2.55	1.35	.....	26	2.40	1.80	1.70	3.35	1.60	.....
11	1.90	1.90	1.95	2.25	1.30	.....	27	2.60	1.80	1.70	3.05	1.45	.....
12	2.05	1.95	1.90	2.10	1.30	.....	28	2.60	1.80	1.70	2.50	1.30	.....
13	2.20	1.90	1.90	2.05	1.35	.....	29	2.45	.....	1.70	2.20	1.20	.....
14	2.30	1.90	2.10	2.05	1.30	.....	30	2.30	.....	1.90	2.05	1.10	.....
15	2.20	1.90	2.75	2.00	1.30	.....	31	2.20	.....	2.40	.....	1.00	.....
16	2.25	1.85	2.70	1.90	1.30	.....							

a Discontinued.

Daily gage height, in feet, of Flint River at Albany, Georgia, for 1897. (a)

Day.	Feb.	Mar.	Apr.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	2.7	9.4	.....	1.3	1.6	2.2	1.5	0.9	1.1
2	3.9	11.5	.....	1.5	1.4	2.0	1.5	.9	1.4
3	4.3	12.4	13.8	1.6	1.2	2.0	1.6	.9	1.5
4	5.7	11.8	13.8	1.0	1.1	2.2	1.7	1.1	1.6
5	6.5	10.0	13.7	1.0	1.0	1.9	1.5	1.5	1.5
6	6.7	8.9	14.2	1.7	1.0	1.7	1.5	1.4	1.5
7	7.2	7.6	14.7	4.2	.9	1.6	1.4	1.3	1.6
8	7.5	8.7	15.1	5.5	1.2	1.5	1.2	1.1	1.6
9	8.3	9.0	15.2	5.7	1.4	1.5	1.2	1.1	1.6
10	9.2	9.0	16.5	5.1	2.4	1.5	1.1	1.1	1.7
11	10.0	10.0	17.9	3.0	2.5	1.4	1.0	1.1	1.7
12	11.5	11.0	17.9	2.5	2.6	1.3	.8	1.2	1.6
13	12.2	11.8	17.9	3.2	2.7	1.3	1.0	1.2	1.6
14	13.0	12.3	16.1	4.2	2.5	1.6	1.0	1.3	1.7
15	14.1	11.6	14.7	5.3	1.7	1.7	1.1	1.2	2.0
16	16.5	10.8	13.1	5.1	1.4	1.9	1.2	1.2	2.6
17	17.8	10.4	10.6	3.2	2.6	2.0	1.2	1.1	2.6
18	19.6	14.9	9.1	2.8	2.2	1.8	1.3	1.3	2.6
19	19.0	19.8	9.1	2.0	2.8	1.6	1.1	1.1	2.7
20	16.4	22.8	8.9	1.7	3.6	1.8	1.1	1.1	2.8
21	15.0	22.7	8.9	2.0	4.1	1.8	1.0	1.2	2.9
22	13.0	22.7	8.9	2.4	5.1	1.6	1.0	1.1	2.9
23	11.0	24.1	8.3	3.6	6.8	1.5	1.2	1.1	3.2
24	10.4	28.7	6.1	4.2	6.3	1.5	1.4	1.3	2.9
25	9.0	31.6	5.1	5.3	6.5	1.4	1.2	1.2	2.9
26	8.9	30.9	4.7	4.9	7.0	1.3	1.2	1.1	2.8
27	7.1	28.0	3.7	3.7	7.2	1.1	1.0	1.1	2.6
28	6.9	26.5	3.7	2.0	6.7	1.1	.8	.9	2.3
29	.....	25.5	3.4	1.9	4.1	1.1	.9	.9	2.3
30	.....	23.6	3.4	1.8	3.2	1.3	.9	1.1	2.3
31	.....	21.3	.....	1.7	2.2	.....	.9	.....	2.3

a No records for May or June.

Daily gage height, in feet, of Flint River at Albany, Georgia, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	1.9	2.2	1.7	1.2	4.3	1.6	3.7	3.4	16.0	0.8	2.0	6.1
2	1.9	2.0	1.6	1.4	3.7	1.4	3.6	4.0	17.2	.8	2.0	7.4
3	1.8	1.9	1.9	1.3	2.9	1.0	3.4	5.8	16.3	1.0	2.00	8.2
4	1.7	1.9	2.2	1.3	2.6	.9	3.4	6.4	15.1	2.0	1.7	9.6
5	1.6	1.9	2.8	1.2	2.3	.8	3.0	7.0	14.3	5.4	1.4	10.3
6	1.6	2.1	3.2	2.3	2.0	.6	3.0	6.7	13.0	6.5	1.4	9.4
7	1.6	2.0	3.7	3.6	1.8	.5	2.6	6.8	12.2	7.8	1.3	9.6
8	1.6	1.8	4.0	5.2	1.8	.5	2.5	7.5	10.3	9.5	1.2	9.8
9	1.7	1.8	4.0	6.1	1.6	.5	2.4	8.0	9.6	10.5	1.4	10.3
10	1.8	1.8	3.2	7.0	1.6	.5	2.4	8.4	10.5	12.0	1.6	11.1
11	1.8	1.7	2.8	6.1	1.6	.6	2.3	8.3	10.8	12.0	2.2	12.0
12	1.9	1.7	2.4	5.0	1.4	.7	2.4	7.6	10.8	10.1	2.6	11.5
13	1.9	1.7	2.2	4.6	1.3	.7	2.6	5.5	10.8	8.8	3.4	10.3
14	1.9	1.7	2.1	3.9	1.3	.7	3.0	5.7	8.6	8.8	3.6	9.4
15	2.0	1.5	1.9	3.6	1.2	.8	3.5	6.1	6.9	8.1	4.2	8.3
16	2.2	1.5	1.9	3.2	1.2	.9	4.0	7.4	5.1	7.2	5.7	7.8
17	1.6	1.4	1.9	2.0	1.2	.9	4.5	8.9	4.0	6.6	7.2	6.7
18	1.8	1.8	2.3	1.9	1.1	.9	4.6	9.9	3.6	6.6	8.7	5.4
19	1.9	2.0	2.6	1.9	1.1	.9	4.6	9.7	3.0	7.0	10.2	4.6
20	2.2	1.8	2.7	1.8	1.0	1.2	4.4	8.9	2.7	7.3	12.5	5.5
21	2.3	1.6	2.4	1.6	1.0	1.4	4.2	7.3	2.7	7.6	13.8	6.3
22	2.3	2.0	2.1	2.0	1.0	2.0	4.0	5.0	2.6	7.0	15.6	7.4
23	2.3	2.3	2.0	2.0	1.1	2.6	3.8	4.5	2.5	6.0	16.1	8.0
24	2.2	2.2	1.8	2.0	1.2	3.0	3.8	3.6	2.3	5.2	15.3	8.0
25	2.2	2.0	1.7	2.6	1.2	3.0	3.5	2.8	2.3	4.6	13.0	8.0
26	2.2	1.9	1.6	3.0	1.6	3.1	3.3	2.0	2.0	4.2	12.0	7.7
27	2.3	1.7	1.5	3.9	1.7	3.2	3.0	2.9	1.7	3.0	12.0	7.3
28	2.3	1.7	1.5	4.6	1.8	3.4	2.8	6.1	1.4	2.5	10.2	7.3
29	2.1	.....	1.3	5.4	1.8	3.5	2.6	10.5	1.0	2.0	8.0	7.0
30	2.0	.....	1.2	5.4	1.8	3.6	2.4	13.1	.8	2.0	6.7	6.8
31	2.1	.....	1.2	.....	1.9	.....	2.8	14.0	.....	2.0	.....	6.8

Daily gage height, in feet, of Chattahoochee River at Oakdale, Georgia, for 1898.

Day.	Upper gage.						Lower gage.					
	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	0.75	1.50	0.40	5.50	1.85	0.25	0.95	2.30	3.10	2.40	3.10	3.70
2	.55	1.30	.40	3.45	1.60	.30	1.10	2.00	20.00	2.50	3.00	3.40
3	.55	1.05	.55	2.60	1.55	.25	.75	1.90	27.75	2.90	2.90	3.60
4	.50	1.00	.80	3.05	1.45	.20	.70	8.50	27.00	15.00	3.00	4.10
5	.55	.95	.85	8.70	1.35	.09	1.40	14.00	22.00	19.25	3.10	5.50
6	.55	1.00	.70	11.15	1.20	.03	1.10	16.00	15.00	23.50	3.80	4.75
7	.55	.95	.55	5.80	1.20	.00	1.85	9.00	12.00	16.25	3.50	4.10
8	.60	.80	.45	3.80	1.10	— .05	3.70	6.00	7.50	7.50	3.80	3.75
9	.65	.75	.35	2.95	1.10	— .02	5.10	3.80	5.50	6.50	2.90	3.40
10	.55	.70	.30	2.35	.90	— .10	4.75	4.30	5.10	5.50	2.80	3.10
11	.55	.70	.30	2.30	.90	— .13	3.50	4.50	4.75	4.90	3.10	3.00
12	.55	.70	.30	2.00	.90	— .20	2.80	5.80	4.00	4.50	3.80	3.30
13	.85	.65	.30	1.75	1.20	.00	1.85	4.10	4.20	4.30	3.10	3.10
14	1.25	.65	.50	1.75	.95	.13	2.50	7.50	3.90	4.00	3.60	2.95
15	1.00	.55	1.05	1.90	.85	.08	4.20	5.50	3.75	3.90	4.10	2.90
16	.85	.55	1.40	1.60	.80	.93	4.10	2.90	3.60	3.70	3.60	2.80
17	.80	.45	3.50	1.45	.70	— .05	2.50	2.85	3.40	3.50	3.70	2.75
18	.75	.60	1.75	1.30	.65	+1.50	1.85	2.40	3.30	5.70	4.05	2.85
19	.75	.90	1.50	1.15	.60	1.65	1.75	2.90	3.20	7.90	4.75	2.95
20	.90	1.05	1.05	1.20	.60	1.53	1.50	6.00	3.10	4.70	5.10	3.25
21	1.50	.75	.85	1.40	.60	1.75	1.40	6.50	3.30	4.30	4.50	3.95
22	2.30	.75	.75	1.35	.55	.35	1.45	4.50	2.90	4.90	3.75	3.50
23	1.50	.55	.55	1.40	1.20	.10	1.50	3.90	3.10	5.30	3.50	7.10
24	1.35	.55	.45	3.65	1.15	— .05	12.40	2.80	5.30	4.10	4.75	8.50
25	2.95	.45	.40	4.55	1.25	— .15	6.30	2.75	3.25	3.80	3.75	5.75
26	7.70	.40	.40	2.65	.80	— .15	3.40	2.90	2.95	3.50	3.50	4.10
27	6.80	.45	.40	2.25	.80	— .20	3.80	7.50	2.80	3.40	3.30	3.75
28	5.05	.60	1.15	2.85	.60	— .05	6.40	4.30	2.70	3.45	3.10	3.50
29	4.35	.....	2.50	2.35	.30	— .07	5.85	2.80	2.60	3.30	3.75	2.95
30	3.05	.....	6.30	1.85	.30	— .10	4.40	3.20	2.50	3.45	4.05	2.75
31	2.70	.....	8.40	.....	.25	.....	3.75	3.20	.....	3.30	.....	3.10

Daily gage height, in feet, of Chattahoochee River at West Point, Georgia, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	2.40	3.05	2.30	6.30	3.20	1.70	1.25	3.40	3.75	1.80	3.38	3.65
2	2.35	2.90	2.30	5.10	3.15	1.65	1.15	2.90	3.90	1.85	3.35	3.60
3	2.20	2.80	2.30	3.40	3.15	1.65	1.10	3.00	12.00	2.90	3.35	5.25
4	2.20	2.60	2.80	3.20	3.00	1.65	1.10	6.00	14.50	5.60	3.30	5.00
5	2.20	2.20	3.10	7.00	2.80	1.50	1.05	7.60	15.30	11.00	3.30	4.00
6	2.15	2.20	3.15	9.20	2.60	1.50	2.20	9.15	18.20	14.50	3.45	4.00
7	2.15	2.20	3.00	9.50	2.40	1.45	2.35	8.20	17.50	12.00	3.50	4.00
8	2.15	2.10	2.90	8.20	2.30	1.45	2.70	6.30	9.00	13.00	3.55	3.80
9	2.15	2.10	2.50	6.00	2.30	1.40	3.50	5.10	6.20	10.00	3.60	3.75
10	2.10	2.10	2.20	5.40	2.30	1.40	4.00	4.30	4.50	7.50	3.75	3.70
11	2.15	2.10	2.10	5.00	2.20	1.40	3.30	6.00	4.00	4.10	3.75	3.60
12	3.00	2.10	2.10	3.50	2.20	1.40	3.00	8.40	3.75	3.90	3.75	3.60
13	2.75	2.05	2.10	2.95	2.20	1.60	2.80	6.75	3.60	3.20	3.85	3.60
14	2.60	2.05	2.10	2.80	2.20	1.65	2.70	5.20	3.40	3.20	3.80	3.40
15	2.60	2.00	3.30	2.60	2.15	1.90	3.00	4.60	3.40	3.15	3.90	3.35
16	2.75	2.00	3.20	2.40	2.15	2.00	3.30	4.00	3.40	3.00	5.60	3.35
17	2.90	2.00	3.00	2.40	2.15	1.80	4.00	4.10	3.20	3.00	5.75	3.35
18	2.95	2.10	2.80	2.35	2.15	1.80	3.60	5.00	3.00	5.00	5.00	3.30
19	2.75	2.60	2.60	2.35	2.10	1.70	3.00	4.20	2.40	5.50	5.00	3.30
20	2.70	2.60	2.40	3.00	2.10	1.55	2.70	3.80	2.00	5.40	4.90	3.25
21	2.80	2.50	2.15	2.75	2.10	1.50	2.20	3.50	1.90	4.90	4.80	3.25
22	3.20	2.50	2.15	2.60	2.10	1.75	2.30	3.40	1.90	4.80	4.30	4.00
23	2.80	2.50	2.15	4.00	2.00	2.00	2.40	3.30	1.90	4.50	4.00	5.65
24	2.90	2.50	2.15	7.00	1.90	2.10	4.00	3.25	2.90	4.50	3.70	5.00
25	2.90	2.45	2.10	5.30	1.85	2.00	7.60	3.20	3.00	4.00	3.70	4.50
26	3.00	2.40	2.10	4.00	2.50	2.10	5.50	3.20	2.75	3.60	3.70	4.40
27	6.00	2.30	2.10	3.60	2.00	2.20	4.10	5.60	2.50	3.40	3.65	4.20
28	5.50	2.30	2.10	3.40	1.80	1.75	4.00	10 60	2.05	3.40	3.60	4.00
29	4.05	.....	3.20	3.40	1.70	1.50	5.60	5.40	1.90	3.40	3.80	3.80
30	3.60	.....	4.10	3.20	1.70	1.40	6.00	3.80	1.80	3.38	3.70	3.80
31	3.10	.....	4.30	.....	1.70	.....	4.20	3.50	.....	3.38	.....	3.75

Daily gage height, in feet, of Etowah River at Canton, Georgia, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	0.50	0.80	0.30	1.60	0.60	0.60	0.30	0.40	0.40	0.40	0.80	1.60
2	.50	.80	.30	1.40	.60	.40	.20	.40	11.50	.40	.80	1.60
3	.30	.80	.60	1.20	.60	.30	.20	2.60	9.00	.30	.70	1.60
4	.30	.70	.60	1.00	.50	.20	.20	3.40	4.00	9.00	.70	2.00
5	.20	.60	.40	2.00	.50	.20	.40	3.00	2.00	13.50	.70	2.40
6	.20	.60	.40	3.60	.40	.20	.40	2.00	3.00	4.00	.80	2.40
7	.30	.60	.40	3.00	.40	.20	.80	3.00	2.40	2.40	.70	2.20
8	.30	.60	.30	1.80	.40	.20	1.80	3.00	1.60	2.00	.60	2.20
9	.30	.50	.20	1.00	.40	.20	.80	2.00	1.40	1.60	.60	2.10
10	.40	.50	.20	.80	.40	.10	.80	4.00	1.40	1.40	.70	2.00
11	.60	.40	.20	.80	.30	.10	.90	6.00	1.60	1.20	.80	2.00
12	.80	.40	.20	.60	.30	.10	2.90	4.00	1.40	1.20	.70	1.80
13	.80	.40	.20	.60	.30	.10	2.00	3.50	1.40	1.10	.70	1.80
14	.60	.40	.10	.60	.30	.70	1.80	2.00	1.00	1.10	.60	1.80
15	.60	.40	.40	.50	.30	.60	1.60	1.80	1.00	1.00	.80	1.70
16	.80	.40	4.00	.50	.30	.60	1.40	1.60	1.00	1.00	.80	1.70
17	.80	.40	3.00	.40	.30	.50	1.20	1.40	.80	1.00	.80	1.70
18	.80	.30	.80	.40	.20	.50	.60	1.20	.80	4.20	.90	1.60
19	.90	.30	.60	.80	.20	.40	.20	1.00	.60	3.00	1.00	1.60
20	.90	.40	.60	.60	.20	.40	.20	.80	.60	2.00	1.20	1.60
21	.80	.50	.40	.70	.20	.40	.20	.60	.40	2.00	1.20	1.60
22	.80	.40	.40	.60	.20	.40	.30	.40	.40	2.00	1.80	1.50
23	.90	.40	.40	.80	.80	.30	.30	.40	.40	1.80	2.00	1.40
24	.90	.40	.30	2.00	.80	.30	7.30	.40	.80	1.60	1.80	1.40
25	2.00	.30	.20	.90	.60	.30	2.00	.40	.60	1.40	1.60	1.40
26	5.60	.30	.20	.80	.60	.30	2.00	.40	.60	1.20	1.60	1.40
27	4.00	.30	.10	.80	.50	.30	1.80	3.60	.40	1.00	1.50	1.40
28	2.60	.30	.20	.80	.40	.30	1.80	2.40	.40	1.00	1.50	1.40
29	1.30	.....	5.00	.60	.40	.30	1.80	1.80	.40	.90	2.00	1.20
30	1.00	.....	4.00	.60	.40	.30	1.80	1.00	.40	.80	1.80	1.20
31	.90	.....	3.00	.....	.80	.....	1.80	.60	.....	.80	.....	1.80

Daily gage height, in feet, of Coosawattee River at Carters, Georgia, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	1.20	2.00	1.40	2.90	2.05	1.20	0.95	2.00	2.00	1.40	2.05	2.50
2	1.10	2.00	1.40	2.90	2.00	1.20	.90	2.05	13.20	1.60	2.00	2.40
3	1.00	2.00	1.30	2.90	1.95	1.10	.90	2.00	11.50	1.75	2.00	2.00
4	1.00	1.95	1.30	3.00	1.90	1.10	.90	2.10	7.00	20.50	2.00	1.90
5	1.00	1.95	1.20	13.50	1.80	1.10	1.00	2.00	5.00	23.00	1.90	1.80
6	.90	1.90	1.10	7.00	1.80	1.05	1.10	2.15	4.00	11.50	2.00	1.70
7	.90	1.90	1.10	5.00	1.80	1.05	1.05	1.95	3.20	5.00	1.90	1.70
8	.95	1.80	1.10	4.20	1.70	1.00	1.10	2.00	3.00	3.50	1.90	1.60
9	.95	1.80	1.05	3.50	1.70	1.00	1.10	2.00	2.50	3.00	1.80	1.70
10	1.10	1.80	1.00	3.00	1.60	1.05	1.00	2.25	2.20	2.90	1.70	1.50
11	1.50	1.70	1.00	2.80	1.60	1.00	1.00	4.70	2.00	2.80	1.80	1.60
12	2.00	1.70	1.05	2.00	1.50	1.10	1.10	3.50	1.90	2.60	1.90	1.60
13	2.50	1.60	1.10	2.00	1.50	1.40	1.10	3.00	1.80	2.40	2.00	1.70
14	2.00	1.60	2.00	1.90	1.45	1.60	1.30	2.50	1.50	2.30	2.10	1.70
15	1.80	1.60	1.90	2.05	1.45	1.70	1.40	2.25	1.40	2.30	2.05	1.60
16	1.80	1.55	1.80	2.10	1.40	1.60	1.10	2.10	1.30	2.20	2.00	1.80
17	1.70	1.55	1.80	2.10	1.40	1.60	1.20	2.50	1.20	2.20	1.90	1.90
18	1.70	1.50	1.70	2.10	1.40	1.50	1.10	3.00	1.25	4.70	1.90	1.80
19	3.05	1.50	1.70	2.05	1.30	1.80	1.10	2.50	1.30	3.20	2.00	1.70
20	2.30	1.50	1.60	2.10	1.30	2.00	1.05	2.30	1.30	3.00	1.90	1.70
21	2.10	1.45	1.60	2.05	1.30	1.80	1.00	9.50	1.20	2.50	1.80	1.80
22	2.50	1.30	1.50	2.00	1.35	1.70	1.00	3.00	1.20	2.50	2.50	2.00
23	2.50	1.30	1.40	2.50	1.35	1.40	1.10	2.00	1.25	2.50	2.40	2.10
24	2.10	1.20	1.40	3.50	1.40	1.20	1.10	1.60	1.30	2.50	2.40	2.00
25	8.00	1.20	1.60	4.00	1.60	1.05	1.20	1.80	1.20	2.40	2.50	2.00
26	6.10	1.20	1.60	3.00	1.50	1.00	1.30	1.60	1.20	2.40	2.30	1.90
27	3.50	1.50	1.50	2.20	1.50	1.00	1.50	1.50	1.20	2.30	2.40	1.90
28	2.80	1.50	1.50	2.20	1.50	1.05	3.50	1.50	1.20	2.30	2.50	1.80
29	2.50	.....	3.50	2.10	1.40	.90	2.50	1.50	1.30	2.20	2.80	1.70
30	2.50	.....	6.50	2.10	1.30	.95	2.00	1.60	1.30	2.10	2.70	1.70
31	2.10	.....	4.00	.....	1.25	.....	3.00	1.80	.....	2.10	.....	1.80

Daily gage height, in feet, of Oostanaula River at Resaca, Georgia, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	3.10	5.15	3.10	10.05	4.50	2.65	1.90	5.90	2.65	2.70	3.65	5.30
2	2.95	4.60	2.90	7.00	4.25	2.30	2.00	4.90	12.80	2.55	3.50	4.80
3	2.70	4.20	3.00	5.70	4.10	2.25	1.90	3.80	19.10	2.50	3.50	4.50
4	2.60	3.90	3.10	5.05	3.90	2.20	1.75	3.80	21.00	6.65	3.50	4.60
5	2.60	3.80	2.05	11.95	3.80	2.10	1.70	7.00	21.00	18.70	3.40	6.60
6	2.60	3.80	2.90	17.70	3.65	2.00	2.20	4.30	19.20	22.00	3.45	6.20
7	2.80	3.80	2.75	15.10	3.55	2.00	2.50	4.10	17.10	23.30	3.80	5.40
8	3.00	3.70	2.70	12.10	3.55	1.90	4.75	3.70	11.60	21.75	3.90	4.90
9	2.85	3.55	2.65	9.75	3.40	1.90	2.90	3.40	7.00	16.70	3.55	4.60
10	2.75	3.45	2.65	5.85	3.35	1.85	3.20	3.70	5.40	6.90	3.40	4.30
11	2.70	3.40	2.65	5.45	3.20	1.85	2.90	7.15	5.00	5.65	3.70	4.30
12	6.85	3.30	2.60	5.50	3.20	1.75	2.60	6.70	4.80	5.15	3.70	4.00
13	6.70	3.30	2.60	5.00	3.10	2.40	2.10	5.40	4.40	4.70	3.70	4.00
14	6.85	3.15	2.70	5.10	3.10	3.50	2.20	4.75	3.95	4.55	4.40	4.00
15	5.85	3.10	4.10	5.50	3.05	2.80	3.40	3.85	3.80	4.30	4.15	3.70
16	6.30	3.05	8.15	5.30	2.90	2.50	3.70	3.40	3.70	4.10	4.85	3.60
17	6.50	2.90	9.40	5.00	2.85	2.40	2.75	4.00	3.50	4.00	4.10	3.60
18	5.10	2.90	5.95	4.60	2.80	3.85	2.40	3.20	3.35	8.00	4.40	3.70
19	4.70	3.00	5.35	4.45	2.75	4.00	2.10	4.30	3.20	9.50	6.75	3.70
20	8.90	3.00	4.60	5.60	2.75	5.30	2.00	4.00	3.10	6.30	7.15	4.70
21	10.65	3.00	4.10	5.65	2.60	5.00	1.90	3.35	3.00	5.00	6.00	5.50
22	9.00	2.95	3.85	4.55	2.60	4.45	1.75	5.30	3.00	5.00	5.15	4.90
23	7.30	2.90	3.60	4.20	2.50	3.90	1.90	3.50	5.35	5.85	7.80	5.00
24	7.05	2.80	3.45	10.60	2.55	2.65	1.80	2.95	4.70	4.90	7.10	5.30
25	8.80	2.80	3.55	9.40	3.00	2.40	2.20	2.90	4.40	4.40	5.95	4.55
26	17.10	2.70	3.95	7.15	2.70	2.20	3.20	3.45	4.30	4.25	5.10	4.25
27	16.00	3.00	3.50	6.50	2.50	2.20	3.40	4.65	3.00	4.40	4.80	4.10
28	13.65	3.25	3.30	5.90	2.35	2.30	5.30	3.75	2.90	4.20	4.40	4.00
29	8.20	.....	6.00	5.30	2.30	2.10	5.25	2.80	2.80	4.00	4.60	3.85
30	6.05	.....	11.85	4.90	2.25	2.00	4.20	2.60	2.70	3.90	5.60	3.80
31	5.50	.....	12.50	.....	2.25	.....	5.20	2.65	.....	3.80	.....	3.80

Daily gage height, in feet, of Coosa River at Rome, Georgia, for 1897.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	1.0	2.8	3.3	7.1	4.1	1.8	1.7	0.8	1.0	0.0	0.5	1.1
2	1.0	9.7	3.2	7.5	4.0	2.3	1.5	.7	.5	.0	.9	1.0
3	1.0	11.5	3.1	8.2	3.5	2.0	1.0	1.2	.3	.0	1.0	1.2
4	1.0	9.6	3.3	9.4	3.3	3.0	0.9	1.0	.5	.1	1.0	2.3
5	1.0	8.2	3.5	14.8	3.0	2.4	2.0	.8	.4	.1	1.0	3.2
6	1.3	5.2	7.6	18.9	3.0	2.0	1.9	.8	.3	.1	.8	3.7
7	1.1	5.0	19.7	17.0	3.0	2.0	1.9	1.9	.3	.1	.8	3.2
8	1.1	4.3	18.9	14.7	2.8	2.0	3.0	2.0	.2	.1	.8	2.2
9	1.0	5.0	15.4	12.1	2.6	2.0	2.1	2.0	.1	.1	.8	1.9
10	1.0	4.4	13.5	9.6	2.6	1.9	1.9	1.6	.0	.1	.7	1.7
11	.9	4.5	12.0	7.2	2.6	1.9	2.5	2.4	.0	.1	.7	1.5
12	.9	7.4	11.5	6.2	3.0	1.9	2.8	1.8	.0	1.1	.7	1.4
13	.9	8.7	18.6	5.8	3.4	1.8	2.0	1.3	.0	1.6	.7	1.3
14	2.8	7.2	21.3	5.0	4.0	1.7	1.6	.8	.0	1.3	.6	2.2
15	6.2	5.5	23.8	6.0	5.0	1.7	1.3	.6	.0	1.0	.6	4.0
16	5.0	4.5	23.4	7.4	4.0	2.0	1.0	.6	.0	.8	.6	3.5
17	3.5	4.0	22.6	7.0	3.3	2.8	5.2	2.1	.0	.7	.6	2.5
18	3.9	3.7	21.4	5.0	2.8	2.3	4.2	3.2	.1	.6	.6	2.2
19	5.0	3.4	19.7	4.5	2.7	2.0	4.8	2.4	.2	.6	.6	1.8
20	3.5	3.0	18.9	4.0	2.6	1.8	8.8	1.4	.2	.6	.6	1.7
21	8.7	4.0	17.7	3.8	2.5	1.6	12.8	1.3	.2	1.5	.6	3.2
22	9.5	3.9	15.3	3.7	2.4	1.5	7.3	1.5	.2	1.3	.5	4.1
23	5.7	5.6	13.7	3.5	2.4	1.5	4.4	1.5	.2	1.0	.5	5.8
24	4.0	11.7	12.9	3.5	2.4	1.4	3.9	1.5	.2	.8	.5	5.3
25	3.5	8.6	9.1	3.5	2.3	1.3	2.6	1 1	.3	.8	.5	3.7
26	3.0	6.7	6.0	3.5	2.2	1.2	2.6	.8	.3	.7	.5	2.8
27	2.5	4.7	5.2	3.4	2.1	1.2	3.8	.5	.4	.7	.5	3.0
28	2.5	3.5	4.8	3.4	2.0	1.0	3.0	.4	.4	.7	.9	2.8
29	2.5	.....	4.5	3.4	2.0	1.1	2.4	.4	.4	.6	1.1	2.3
30	2.3	.....	4.2	3.2	1.9	2.0	1.4	.4	.4	.5	1.1	2.0
31	2.2	.....	4.0	.....	1.9	.....	1.2	.5	.....	.5	.....	2.0

Daily gage height, in feet, of Coosa River at Rome, Georgia, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	1.8	3.6	1.2	9.0	2.8	1.4	1.2	4.8	2.0	2.0	2.2	4.2
2	1.8	3.1	1.2	6.1	2.6	1.4	1.0	4.4	7.8	2.0	2.2	4.0
3	1.7	2.8	1.2	4.2	2.4	1.4	1.0	3.2	21.7	2.0	2.2	3.8
4	1.7	2.6	1.2	3.6	2.3	1.4	1.0	4.4	24.3	4.9	2.2	3.8
5	1.6	2.4	1.2	9.9	2.2	1.3	1.0	8.0	22.2	22.0	2.0	4.3
6	1.6	2.2	1.2	17.2	2.1	1.3	1.3	5.6	20.0	23.8	2.2	5.0
7	1.3	2.0	1.2	14.5	2.0	1.3	2.0	4.4	17.6	19.0	2.6	4.3
8	1.3	1.8	1.2	10.9	2.0	1.3	2.8	4.4	16.4	18.4	2.4	4.0
9	1.3	1.8	1.2	7.0	2.0	1.3	3.2	3.4	9.7	16.6	2.3	3.7
10	1.3	1.7	1.2	4.1	2.0	1.3	1.7	3.0	5.0	14.0	2.1	3.4
11	1.4	1.5	1.2	4.0	2.0	1.3	2.8	9.9	5.4	5.6	2.0	3.3
12	2.0	1.5	1.2	3.8	1.9	1.2	2.0	7.2	4.6	4.2	2.0	3.3
13	4.0	1.3	1.2	3.6	1.8	1.4	1.8	4.2	3.8	3.8	2.0	3.2
14	4.0	1.3	1.3	3.5	1.8	1.8	1.6	3.4	3.2	3.7	2.3	3.0
15	3.8	1.3	1.6	3.5	1.7	1.8	3.7	3.0	3.0	3.5	2.3	3.0
16	3.6	1.3	3.7	3.4	1.6	1.7	3.7	2.5	2.9	3.2	2.9	2.8
17	3.6	1.2	7.3	3.0	1.5	1.8	2.2	2.0	2.7	3.1	2.9	2.7
18	3.2	1.2	5.8	3.0	1.5	1.8	1.9	2.2	2.5	6.5	4.0	2.6
19	2.8	1.2	3.7	3.0	1.5	2.2	1.7	2.2	2.3	9.0	5.0	2.6
20	4.4	1.2	3.0	3,6	1.4	3 6	1.6	3.2	2.2	6.0	4.5	2.6
21	6.5	1.2	2.5	3.6	1.4	3.2	1.5	2.8	2.2	4.2	5.0	2.8
22	6.4	1.2	2.5	3.2	1.4	3.0	1.4	3.9	2.3	3.9	4.0	2.9
23	5.0	1.2	2.3	3.0	1.4	2.8	1.3	2.2	2.6	4.0	5.0	3.2
24	4.5	1.2	2.2	7.2	1.4	2.6	1.8	2.2	4.1	3.9	7.0	3.6
25	7.0	1.2	2.1	8.2	1.4	2.0	3.7	1.9	3.1	3.5	4.7	3.0
26	14.0	1.2	2.0	6.0	1.4	1.8	3.8	2.7	3.0	3.3	3.9	2.9
27	14.6	1.2	1.9	4.6	1.4	1.8	2.9	4.0	2.7	3.1	4.5	2.7
28	11.6	1.2	1.8	4.0	1.4	1.8	3.7	4.4	2.5	3.0	4.3	2.6
29	8.6	.....	2.0	3.7	1.4	1.6	4.2	3.4	2.3	2.8	4.3	2.5
30	4.6	.....	8.5	3.2	1.4	1.4	4.1	2.0	2.1	2.6	3.9	2.4
31	3.9	.....	11.4	.....	1.4	.....	4.2	2.3	.....	2.4	.....	2.4

Daily gage height, in feet, of Coosa River at lower gage, Lock No. 4, 3 miles above Riverside, Alabama, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	3.0	6.3	1.5	8.2	4.5	1.1	0.9	4.8	2.1	1.4	3.0	4.5
2	3.0	4.9	1.5	9.0	4.0	1.0	.8	4.5	1.8	1.4	2.8	4.4
3	2.4	4.2	1.8	8.0	3.6	1.0	.7	4.5	2.0	1.6	2.7	4.3
4	2.1	3.4	1.8	6.2	3.3	1.1	.7	4.5	6.4	2.0	2.6	4.1
5	1.7	3.4	1.7	7.1	3.1	1.1	.4	3.7	10.4	8.1	2.4	4.0
6	1.6	3.1	1.6	10.5	2.8	1.0	.5	4.3	12.0	12.8	2.5	4.3
7	1.5	2.8	1.7	12.1	2.8	.9	.7	6.5	12.7	13.6	2.4	4.6
8	1.5	2.7	1.7	12.3	2.4	.8	.7	6.6	13.0	18.0	2.5	4.8
9	1.4	2.6	1.5	11.7	2.3	.7	1.0	5.0	13.5	17.0	2.9	4.3
10	1.4	2.6	1.5	10.0	2.2	.7	1.6	4.9	12.4	15.0	3.0	4.0
11	1.6	2.5	1.5	8.0	2.2	.6	2.7	4.8	10.0	14.8	2.8	3.6
12	1.9	2.4	1.4	6.0	2.2	.6	2.6	5.7	6.7	13.5	2.6	3.3
13	2.0	2.3	1.4	5.0	2.0	.7	2.1	8.0	5.5	9.4	2.8	3.2
14	2.5	2.3	1.4	4.5	1.9	.9	1.7	7.0	4.6	6.0	3.3	3.1
15	3.6	2.2	1.4	4.2	1.9	.9	2.0	5.3	3.7	4.6	3.3	3.0
16	4.1	2.0	1.7	4.0	1.9	1.0	2.4	4.1	3.1	4.1	3.4	2.8
17	4.2	1.9	2.8	3.9	1.7	1.0	3.4	3.3	2.8	3.7	3.6	2.7
18	4.1	1.8	4.0	3.7	1.5	1.0	3.4	2.8	2.7	4.9	3.5	2.5
19	3.9	1.8	5.7	3.7	1.4	1.3	2.7	2.5	2.4	6.5	3.6	2.6
20	4.1	1.8	5.4	6.2	1.4	1.2	1.9	2.4	2.3	7.6	4.2	5.1
21	4.6	1.8	4.2	6.9	1.4	1.5	1.4	2.4	2.0	7.9	4.8	5.7
22	6.3	1.8	3.4	6.0	1.4	2.1	1.4	2.6	2.0	7.0	5.9	5.5
23	7.0	1.7	3.0	6.2	1.4	2.5	1.0	2.5	2.8	6.0	7.3	5.0
24	7.0	1.7	2.7	6.8	1.3	2.5	1.0	2.5	5.0	5.0	6.8	4.6
25	7.0	1.6	2.4	8.2	1.2	2.0	1.1	2.7	4.8	4.5	6.5	4.3
26	9.5	1.6	2.2	8.9	1.2	1.6	1.2	2.2	3.9	4.4	6.2	4.2
27	11.0	1.6	2.1	8.8	1.2	1.6	2.3	1.8	3.4	4.0	5.4	4.0
28	11.7	1.5	2.1	7.2	1.5	1.6	3.6	1.7	3.2	3.8	4.6	3.7
29	11.6	.....	2.1	5.9	1.1	1.4	3.6	1.7	2.8	3.6	4.4	3.4
30	10.4	.....	3.8	5.0	.9	1.1	3.8	3.8	2.0	3.2	4.4	3.2
31	8.6	.....	5.7	.....	.8	.....	4.9	3.0	.....	3.0	.....	3.1

Daily gage height, in feet, of Coosa River at Riverside, Alabama, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	2.30	6.00	1.65	6.80	3.90	1.30	1.15	4.25	2.20	2.20	2.60	3.70
2	2.15	5.25	1.70	7.50	3.60	1.25	1.05	4.00	1.80	1.80	2.50	4.00
3	2.10	4.00	1.80	6.80	3.30	1.20	1.00	4.10	1.75	1.70	2.50	3.90
4	2.00	3.25	1.80	5.50	3.05	1.20	.95	4.00	5.80	2.00	2.45	3.70
5	1.90	3.00	1.80	5.80	2.90	1.30	.95	3.30	9.30	6.80	2.40	3.70
6	1.85	2.80	1.75	9.30	2.70	1.25	.90	4.00	10.20	11.20	2.40	3.90
7	1.75	2.75	1.70	10.50	2.55	1.20	.95	5.50	11.00	11.90	2.40	4.00
8	1.70	2.70	1.70	10.80	2.40	1.10	1.00	5.30	11.30	15.80	2.40	4.00
9	1.65	2.60	1.65	10.40	2.30	1.05	1.15	4.50	11.60	14.70	2.45	3.70
10	1.60	2.50	1.65	8.90	2.20	1.05	1.65	4.30	10.80	12.50	2.55	3.30
11	1.60	2.40	1.60	7.50	2.15	1.00	2.15	4.50	8.70	12.00	2.75	3.25
12	1.65	2.30	1.60	6.00	2.10	1.48	2.15	4.70	5.80	11.20	2.75	3.10
13	1.80	2.30	1.70	5.00	2.00	1.10	2.10	6.70	4.75	8.80	2.70	3.00
14	2.00	2.20	1.80	4.40	1.95	1.25	2.15	5.90	4.10	5.50	2.65	2.90
15	3.10	2.10	2.00	4.00	1.90	1.15	2.05	4.70	3.40	4.40	2.70	2.80
16	3.00	2.00	2.25	3.70	1.85	1.00	2.30	3.70	3.00	3.60	2.80	2.65
17	2.80	1.95	3.00	3.50	1.80	1.65	3.10	3.00	2.70	3.00	3.00	2.60
18	2.60	1.90	4.75	4.00	1.75	1.70	3.05	2.75	2.50	3.50	3.15	2.60
19	2.80	1.85	5.50	5.10	1.70	1.65	2.50	2.55	2.25	5.40	3.25	2.70
20	3.00	1.80	4.70	5.80	1.60	1.55	1.90	2.45	2.20	6.40	3.70	2.90
21	4.10	1.80	4.00	5.50	1.70	1.95	1.65	2.40	2.15	6.30	4.20	4.00
22	5.80	1.80	3.25	4.00	1.65	2.10	1.50	2.40	2.20	6.00	5.15	3.80
23	6.05	1.75	3.00	4.50	1.55	2.30	1.35	2.35	2.55	5.80	7.00	3.40
24	6.50	1.75	2.75	5.75	1.50	2.50	1.25	2.30	3.55	5.00	5.90	3.00
25	7.20	1.70	2.30	7.10	1.45	2.05	1.20	2.15	4.30	4.35	5.20	2.75
26	9.00	1.70	2.15	7.80	1.40	1.75	1.40	2.00	3.90	4.00	4.90	2.70
27	10.20	1.70	2.00	7.45	1.55	1.50	2.35	1.80	3.40	3.75	4.60	2.50
28	10.65	1.65	2.00	6.45	1.70	1.60	3.15	2.00	3.15	3.30	4.20	2.40
29	10.45	.....	2.30	5.50	1.60	1.45	3.10	2.50	3.00	3.00	4.00	2.30
30	9.45	.....	3.00	4.75	1.45	1.30	3.40	3.00	2.75	2.75	3.80	2.30
31	7.55	.....	4.50	.....	1.35	.....	4.00	2.60	.....	2.70	.....	2.40

Daily gage height, in feet, of Coosa River, at Lock No. 5 (Collins Ferry, Alabama), for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	1.0	3.6	0.5	5.0	2.4	0.4	0.3	2.5	1.0	0.7	1.4	2.4
2	.9	2.6	.5	5.7	2.0	.3	.1	2.5	.7	.7	1.3	2.4
3	.8	2.0	.5	5.1	1.8	.3	.1	2.3	.8	.6	1.2	2.4
4	.7	1.9	.5	3.8	1.6	.3	.1	2.3	3.1	1.5	1.2	2.3
5	.6	1.6	.6	4.5	1.4	.2	.1	1.9	7.1	5.2	1.2	2.0
6	.6	1.4	.6	7.5	1.3	.2	.1	2.2	8.5	10.3	1.4	2.2
7	.5	1.3	.6	8.6	1.2	.1	.1	3.8	8.9	10.3	1.3	2.4
8	.5	1.2	.6	8.8	1.1	.1	.8	3.5	9.4	14.7	1.2	2.3
9	.5	1.2	.5	8.4	1.0	.1	.4	3.1	9.5	13.7	1.3	2.5
10	.5	1.1	.5	7.2	.9	.1	.6	2.7	8.8	12.7	1.4	2.0
11	.5	1.1	.5	5.3	.9	.1	.8	3.0	7.1	11.0	1.4	1.9
12	.7	1.0	.5	3.5	.9	.1	.4	3.2	4.1	9.9	1.3	1.7
13	.8	1.0	.5	2.8	.8	.8	.8	5.0	3.1	7.0	1.5	1.6
14	.9	.9	.5	2.4	.8	.3	.9	4.3	2.5	4.4	1.7	1.5
15	1.6	.8	.5	2.3	.7	.3	1.0	3.0	1.9	2.6	1.7	1.5
16	2.0	.8	.6	2.0	.7	.3	1.0	2.2	1.5	2.1	1.7	1.4
17	2.1	.7	1.2	1.9	.7	.5	1.5	1.7	1.3	1.9	1.8	1.3
18	2.1	.7	1.8	.8	.6	.6	1.6	1.3	1.2	2.5	1.8	1.3
19	1.9	.6	3.0	1.8	.6	.4	1.2	1.5	1.1	3.6	2.0	1.3
20	2.1	.6	3.0	3.2	.5	.4	.8	1.4	1.0	4.6	2.7	2.5
21	2.7	.6	2.3	4.0	.5	.4	.7	1.3	.9	5.0	2.6	3.3
22	3.5	.7	1.6	3.5	.5	.7	.6	1.2	.9	4.4	3.3	3.2
23	4.0	.7	1.3	2.9	.5	1.0	.3	1.1	1.2	3.6	4.2	2.8
24	4.1	.6	1.1	4.1	.5	1.1	.3	1.0	2.7	2.8	4.3	2.5
25	4.1	.6	1.0	5.0	.5	.8	.3	1.3	2.6	2.5	4.0	2.3
26	6.5	.6	.9	5.6	.5	.6	.5	1.2	2.0	2.1	3.7	2.2
27	7.7	.6	.9	5.3	.4	.4	1.3	1.0	1.6	2.0	3.1	2.1
28	8.4	.5	.8	4.4	.5	.5	1.6	.8	1.1	1.8	2.6	1.8
29	8.2	.....	.8	3.4	.5	.5	1.6	1.1	1.0	1.6	2.4	1.6
30	7.3	.....	1.5	2.9	.4	.4	1.8	1.9	.8	1.5	2.4	1.5
31	5.5	.....	3.3	.....	.4	.....	2.0	1.4	.....	1.4	.....	1.6

Daily gage height, in feet, of Coosa River 3 miles above Wetumpka, Alabama, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	3.0	7.3	1.9	5.1	4.6	0.9	1.4	5.3	2.0	1.9	2.4	4.8
2	2.0	5.9	2.0	6.7	4.1	.9	.9	5.8	2.0	1.6	2.6	4.4
3	1.9	5.0	2.0	7.0	3.7	.9	.6	6.1	1.7	1.4	2.6	5.4
4	1.8	4.3	1.8	7.5	3.5	.9	.5	6.7	1.7	4.8	2.6	5.4
5	1.7	3.5	1.7	8.7	3.2	.9	.7	5.3	1.7	5.8	2.5	4.9
6	1.7	4.3	1.8	9.3	3.0	.8	.9	4.1	3.1	8.4	2.4	4.4
7	1.6	4.0	1.7	12.1	2.7	.8	1.2	4.6	4.7	12.5	2.9	4.0
8	1.5	3.8	1.7	11.3	2.4	.7	1.6	4.8	5.9	12.8	2.9	4.2
9	1.7	3.5	1.6	10.5	2.4	.5	1.9	5.0	7.5	17.5	2.5	4.3
10	1.7	3.0	1.6	9.9	2.2	.5	1.8	5.7	10.1	16.0	3.5	4.7
11	1.8	2.7	1.6	8.1	2.0	.5	1.5	9.8	9.9	13.8	4.6	4.2
12	1.9	2.3	1.4	7.3	2.0	.5	1.4	8.6	8.5	12.2	3.7	3.9
13	2.1	2.2	1.4	6.1	1.8	.5	1.6	7.4	7.6	10.0	3.2	3.7
14	2.3	2.0	1.4	5.0	1.7	.3	1.7	7.8	6.8	8.2	4.0	3.5
15	2.5	2.0	1.3	4.3	1.7	.3	2.5	7.0	4.6	5.5	4.3	3.2
16	1.8	1.8	1.2	3.7	1.7	.8	3.0	6.3	3.8	4.2	4.0	3.0
17	1.8	1.7	1.2	3.6	1.6	.9	1.8	5.2	3.0	1.3	3.9	2.9
18	2.0	1.6	1.4	3.4	1.6	1.0	1.8	4.7	2.6	2.7	4.1	2.9
19	2.4	1.4	1.8	3.7	1.4	1.2	2.1	4.1	2.3	4.0	6.0	3.0
20	2.9	1.4	3.4	3.9	1.4	1.2	2.6	3.3	2.1	5.2	5.0	5.8
21	3.4	1.4	2.9	4.3	1.3	1.5	2.9	2.5	1.9	6.8	4.8	5.9
22	4.8	1.3	2.7	5.7	1.3	1.9	1.4	2.4	1.9	7.0	5.3	5.9
23	5.5	1.3	2.7	5.9	1.3	2.3	1.2	2.4	1.9	6.3	7.3	5.7
24	6.1	1.3	2.4	7.1	1.1	2.5	1.4	2.1	1.8	4.5	7.4	5.2
25	7.5	1.3	2.4	7.9	1.1	2.5	1.4	2.9	3.8	4.7	6.6	4.7
26	8.1	1.2	2.2	8.1	1.0	2.3	2.1	3.2	3.8	4.2	6.0	4.4
27	8.7	1.8	2.0	7.0	.9	2.0	1.7	3.8	3.5	4.1	5.8	4.0
28	9.5	1.8	1.8	6.3	.9	2.0	2.0	2.8	3.0	3.7	5.2	4.0
29	10.0	.....	1.8	5.7	.9	1.8	3.2	2.8	2.5	3.5	5.3	3.7
30	9.0	.....	2.7	5.2	.9	1.5	4.2	2.4	2.3	2.6	5.3	3.5
31	8.5	.....	3.9	.....	.9	.....	4.9	2.4	.....	2.5	.....	3.5

Daily gage height, in feet, of Tallapoosa River at Milstead, Alabama, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	2.90	2.30	1.90	4.80	2.60	1.10	1.50	3.60	4.30	1.30	2.30	4.90
2	1.90	2.20	1.80	3.90	2.30	1.10	1.30	2.90	3.20	1.30	2.20	4.40
3	1.80	2.10	1.90	3.10	2.20	1.10	1.20	2.80	2.70	1.40	2.20	7.70
4	1.70	2.00	2.40	3.00	2.10	1.10	1.10	11.50	2.70	16.00	2.10	10.00
5	1.70	2.00	2.90	17.00	2.00	1.10	1.20	14.00	4.00	32.00	2.10	8.60
6	1.80	2.00	2.80	18.80	2.00	1.10	1.30	8.90	4.60	23.50	2.20	6.80
7	1.80	2.00	2.50	12.10	1.90	1.00	1.70	10.10	6.00	16.40	2.70	5.60
8	1.80	2.90	2.30	7.10	1.90	.90	2.90	8.50	5.60	22.80	4.20	4.80
9	1.90	2.00	2.20	5.20	1.80	.90	4.90	7.90	4.50	14.00	2.80	4.60
10	1.90	1.90	2.00	4.00	1.80	.90	3.60	5.30	3.50	7.90	3.00	6.70
11	1.90	1.90	2.00	3.40	1.70	.80	4.40	17.30	2.90	5.90	7.10	6.10
12	2.40	1.90	2.00	3.10	1.70	.90	2.00	22.60	2.60	4.90	5.10	5.50
13	2.40	1.90	1.90	3.00	1.70	1.20	1.70	10.10	2.50	3.80	5.00	5.00
14	2.60	1.90	1.90	2.90	1.60	1.20	2.70	7.70	2.40	3.40	5.90	4.40
15	2.40	1.80	2.70	2.80	1.60	1.10	3.50	6.10	2.20	3.00	5.50	4.00
16	2.40	1.80	2.60	2.60	1.60	1.20	5.10	4.20	2.00	2.70	5.40	3.80
17	2.40	1.80	2.50	2.40	1.60	2.10	2.40	3.40	1.80	2.60	6.20	3.60
18	2.30	1.90	2.60	2.40	1.60	1.80	2.80	2.80	1.70	4.40	6.10	3.40
19	2.20	2.20	2.50	2.20	1.50	1.40	3.05	2.60	1.60	5.00	14.40	4.30
20	2.20	2.30	2.40	2.40	1.50	1.40	2.30	2.80	1.60	4.40	12.20	7.60
21	3.10	2.30	2.20	2.80	1.40	1.40	1.90	2.50	1.50	3.70	10.00	7.00
22	3.10	2.10	2.00	2.70	1.40	3.00	1.60	2.30	1.50	3.30	8.00	5.20
23	3.00	2.00	1.90	2.80	1.30	2.40	1.60	2.20	1.50	3.10	10.00	4.40
24	2.90	2.00	1.90	14.50	1.30	2.20	1.50	2.00	1.60	2.70	8.80	6.40
25	2.60	1.90	1.80	11.60	1.20	2.10	1.50	2.10	1.80	2.60	7.90	6.00
26	2.90	1.80	1.80	5.90	1.20	1.80	2.50	8.10	2.00	2.50	5.30	4.60
27	3.60	1.90	1.80	4.30	1.20	1.50	2.60	10.20	1.80	2.40	4.60	4.20
28	3.90	1.90	1.70	3.30	1.30	1.80	4.10	8.40	1.60	2.40	4.10	3.90
29	3.10	.....	2.20	2.95	1.20	2.70	2.80	7.00	1.50	2.40	4.90	3.80
30	2.65	.....	4.20	2.80	1.20	1.90	2.90	5.20	1.50	2.40	5.40	3.70
31	2.40	.....	5.30	.....	1.10	.....	3.80	5.10	.....	2.30	.....	4.00

Daily gage height, in feet, of Black Warrior River at Tuscaloosa, Alabama, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	7.10	21.68	3.67	25.50	11.34	0.23	0.66	2.45	1.20	−0.60	0.90	5.40
2	6.28	18.30	3.78	22.40	9.82	.08	.43	1.95	.82	— .70	.70	5.50
3	5.52	14.90	4.03	18.50	8.67	.23	.30	2.45	.70	— .80	.60	5.40
4	4.96	12.12	4.05	15.31	7.68	.27	.53	2.80	.30	— .90	.40	5.00
5	4.41	10.15	3.98	20.82	6.88	.27	.16	2.96	.00	−1.00	.00	4.70
6	4.17	9.42	3.90	38.70	6.20	.15	.10	3.90	—.10	— .90	.30	4.50
7	4.13	8.90	3.57	38.55	5.59	.02	—.18	3.40	—.30	— .90	.50	5.00
8	4.18	8.43	3.33	32.83	5.00	—.10	—.04	3.10	—.20	— .70	.40	5.00
9	4.17	7.84	3.12	27.70	4.50	—.29	—.04	3.98	.00	— .30	.40	4.70
10	3.97	7.30	3.00	23.04	4.20	—.41	+.10	6.20	.20	+2.00	.50	4.20
11	4.00	6.68	2.90	19.50	3.91	—.54	.08	12.20	.40	3.30	.50	3.70
12	4.18	6.30	2.83	17.03	3.50	—.62	—.07	14.10	.20	2.60	.40	3.30
13	6.70	6.20	2.80	15.01	3.21	—.71	—.10	10.60	.00	2.00	.50	3.00
14	9.70	6.08	3.00	12.93	2.88	—.62	—.07	7.30	—.30	1.40	.80	2.80
15	11.97	5.88	4.80	11.65	2.58	—.53	—.11	5.00	—.30	1.00	1.10	2.60
16	11.71	5.40	8.00	10.78	2.30	—.38	—.07	3.50	—.40	.80	1.30	2.50
17	15.00	5.00	15.40	9.60	2.08	—.48	—.14	2.62	—.60	.40	1.50	2.40
18	15.53	4.90	14.10	8.68	1.97	—.56	.00	1.91	—.70	.80	1.60	2.10
19	14.32	4.83	11.92	8.15	1.64	—.30	1.24	1.50	—.70	.80	1.90	4.40
20	24.50	4.84	10.06	27.80	1.43	—.21	1.30	1.46	—.80	1.20	2.20	18.80
21	33.54	4.70	8.82	31.11	1.23	.00	1.12	1.12	—.90	3.10	2.50	23.90
22	31.42	4.48	7.80	28.45	1.07	.07	.88	1.28	—.50	3 80	4.00	21.30
23	28.50	4.30	6.96	23.77	1.00	.18	.47	1.20	—.60	4.10	8.60	17.40
24	30.38	4.00	6.30	22.72	.93	.30	1.08	.90	—.70	4.80	11.70	13.30
25	30.12	3.83	6.00	24.04	.78	.17	1.95	.50	—.80	4.30	11.60	10.50
26	42.50	3.64	5.96	22.62	.57	.06	2.50	1.10	—.90	3.90	9.50	8.60
27	43.48	3.56	5.53	19.67	.43	1.30	2.00	1.02	—.90	2.90	7.40	7.30
28	39.41	3.72	5 12	17.12	.43	1.10	1.80	.98	—.80	2.30	5.90	6.20
29	33.80	.....	5.23	15.05	.52	.46	2.08	1.30	—.80	2.00	5.50	5.60
30	28.50	.....	13.40	13.03	.44	.68	2.55	1.52	—.60	1.40	5.30	5.00
31	24.90	.....	25.68	.....	.30	.....	2.86	1.56	.....	1.10	.....	4.70

List of discharge measurements.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
1898.				*Feet.*	*Sec.-feet.*
Feb. 26	Flint River	Molina, Ga.	Max Hall	1.80	458
Apr. 21	do	do	do	2.00	877
May 28	do	do	do	1.25	313
Jan. 21	Chattahoochee River.	Oakdale, Ga.	do	1.71	2,165
Feb. 28	do	do	do	.65	1,446
Apr. 5	do	do	do	9.95	12,578
May 16	do	do	do	.85	1,501
May 26	do	do	do	.80	1,459
May 28	do	do	B. M. Hall	1.30	*a* 1,068
June 1	do	do	Max Hall	1.35	*a* 1,137
June 30	do	do	do	.80	*a* 782
July 23	do	do	do	2.45	*a* 2,.92
Aug. 20	do	do	do	4.90	*a* 4,157
Sept. 5	do	do	do	20.10	*a* 24,414
Nov. 19	do	do	do	4.77	*a* 4,735
Jan. 18	do	West Point, Ga.	do	2.45	2,648
Feb. 18	do	do	do	2.43	2,464
Mar. 17	do	do	do	3.08	3,571
Apr. 6	do	do	do	9.20	19,886
Apr. 26	do	do	do	4.52	6,704
May 17	do	do	do	2.15	1,975
June 11	do	do	do	1.40	1,161
July 6	do	do	do	2.27	2,451
Aug. 5	do	do	do	8.82	18,506
Sept. 2	do	do	do	7.55	15,067
Sept. 3	do	do	do	11.25	25,212
Oct. 5	do	do	B. M. Hall	13.90	37,579
Oct. 29	do	do	do	3.38	4,409
Nov. 29	do	do	do	4.00	5,394
Jan. 13	Etowah River	Canton, Ga	Max Hall	.60	761
Mar. 5	do	do	do	.33	621
Mar. 29	do	do	B. M. Hall	5.60	5,124
May 20	do	do	do	.60	627
June 4	do	do	Max Hall	.22	495
July 19	do	do	B. M. Hall	.25	413
Aug. 30	do	do	do	.65	1,062
Sept. 6	do	do	do	3.25	3,190
Sept. 7	do	do	do	2.00	2,104
Nov. 18	do	do	do	.90	1,223
Dec. 10	do	do	do	.70	1,064
Jan. 16	Coosawattee River	Carters, Ga	Olin P. Hall	5.70	3,052
Mar. 18	do	do	do	1.80	697
Mar. 30	do	do	do	5.87	3,079
Do	do	do	do	5.35	2,782
May 28	do	do	do	1.36	495
June 25	do	do	do	1.12	385
July 28	do	do	do	2.55	1,019
Aug. 25	do	do	Max Hall	1.77	686
Oct. 5	do	do	Olin P. Hall	12.10	4,909
Nov. 22	do	do	do	4.05	2,008
May 21	Oostanaula River	Resaca, Ga	do	2.65	1,100
July 29	do	do	do	5.41	2,567
Aug. 20	do	do	Max Hall	3.79	1,811
Aug. 27	do	do	do	4.65	2,397
1896.					
Sept. 29	Coosa River	Rome, Ga	do	.20	1,209
1897.					
May 7	do	do	do	2.75	4,646
Oct. 5	do	do	do	—.15	990
1898.					
May 11	do	do	do	1.90	2,946
Sept. 17	do	do	B. M. Hall	2.60	3,913
Oct. 11	do	do	J. C. Conn	5.05	8,324
Oct. 22	do	do	B. M. Hall	4.10	6,489
Nov. 30	do	do	J. C. Conn	3.90	6,059
Jan. 27	do	Riverside, Ala	Max Hall	10.00	30,359
Mar. 9	do	do	do	1.60	3,538
May 3	do	do	do	3.22	7,758
May 25	do	do	B. M. Hall	1.39	3,172
Aug. 3	do	do	Max Hall	3.92	9,524
Sept. 7	do	do	do	11.05	37,811
Oct. 19	do	do	J. C. Conn	6.80	14,484
Nov. 22	do	do	B. M. Hall	5.85	16,384
Jan. 19	Tallapoosa River	Milstead, Ala	Max Hall	2.13	1,880
Feb. 19	do	do	do	2.20	2,045
Mar. 18	do	do	do	2.56	2,646
Apr. 26	do	do	do	5.83	6,648
May 17	do	do	do	1.55	1,059
June 22	do	do	do	3.05	3,421
July 7	do	do	do	1.62	1,262
Aug. 5	do	do	do	13.67	15,295
Sept. 3	do	do	do	2.76	3,010
Nov. 29	do	do	B. M. Hall	5.16	5,477

a 1 mile below Oakdale, at Mason and Turner's ferry.

Rating tables.

Molina.		Oakdale. *a*		Oakdale. *b*		West Point.		Canton. *c*		Canton. *d*	
Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-f*
1.0	275	—0.4	820	0.7	780	1.2	1,000	0.0	270	0.0	657
1.1	285	— .2	920	0.8	780	1.6	1,380	.2	380	.2	788
1.2	301	.0	1,020	0.9	840	2.0	1,840	.4	560	.4	922
1.3	324	.2	1,130	1.0	900	2.4	2,380	.6	742	.6	1,059
1.4	354	.4	1,240	1.5	1,215	2.8	3,000	.8	924	.8	1,200
1.5	390	.6	1,350	2.0	1,560	3.2	3,700	1.0	1,106	1.0	1,347
1.6	436	.8	1,470	3.0	2,300	3.6	4,480	1.2	1,288	1.2	1,498
1.7	496	1.0	1,590	4.0	3,250	4.0	5,370	1.4	1,470	1.4	1,655
1.8	566	1.5	1,920	5.0	4,400	4.4	6,400	1.6	1,652	1.6	1,818
1.9	646	2.0	2,270	6.0	5,700	4.8	7,490	1.8	1,834	1.8	1,984
2.0	736	2.5	2,650	7.0	7,000	5.2	8,592	2.0	2,016	2.0	2,150
2.2	980	3.0	3,070	8.0	8,300	5.6	9,696	2.2	2,198	2.2	2,316
2.4	1,305	3.5	3,530	9.0	9,600	6.0	10,800	2.4	2,380	2.4	2,483
2.6	1,645	4.0	4,030	10.0	10,900	6.4	11,904	2.6	2,562	2.6	2,648
2.8	1,985	4.5	4,580	11.0	12,200	6.8	13,008	2.8	2,744	2.8	2,814
3.0	2,325	5.0	5,160	12.0	13,500	7.2	14,112	3.0	2,926	3.0	2,980
3.2	2,665	5.5	5,850	13.0	14,800	7.6	15,240	3.5	3,375	3.5	3,395
3.4	3,005	6.0	6,600	14.0	16,100	8.0	16,400	4.0	3,800	4.0	3,810
3.6	3,350	6.5	7,350	15.0	17,400	8.5	17,850	4.5	4,220	4.5	4,225
3.8	3,690	7.0	8,100	16.0	18,700	9.0	19,300	5.0	4,640	5.0	4,640
4.0	4,030	7.5	8,850	17.0	20,000	9.5	20,750	5.5	5,055	5.5	5,055
4.2	4,370	8.0	9,600	18.0	21,300	10.0	22,200	6.0	5,470	6.0	5,470
4.4	4,710	8.5	10,350	19.0	22,600	10.5	23,650	6.5	5,885	6.5	5,885
4.6	5,050	9.0	11,100	20.0	23,900	11.0	25,100	7.0	6,300	7.0	6,300
4.8	5,390	9.5	11,850	22.0	26,500	11.5	26,590	7.5	6,715	7.5	6,715
5.0	5,730	10.0	12,600	24.0	29,100	12.0	28,800	8.0	7,130	8.0	7,130
.....	.....	10.5	13,350	26.0	31,700	12.5	31,110	8.5	7,545	8.5	7,545
.....	.....	11.0	14,100	28.0	34,300	13.0	33,410	9.0	7,960	9.0	7,960
.....	.....	.....	.....	.....	.....	13.5	35,710	.....	.....	.....	.....
.....	.....	.....	.....	.....	.....	14.0	38,080	.....	.....	.....	.....

a Applicable from January 1 to June 30, 1898. Gage heights refer to upper gage.
b Applicable from July 1 to December 31, 1898. Gage heights refer to lower gage.
c Applicable from October 11, 1897, to July 23, 1898.
d Applicable from July 24, 1898, to December 31, 1898.

Carters.		Resaca.		Rome.		Riverside.		Milstead.		Tuscaloosa.	
Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*
1.0	355	1.0	350	0.0	1,070	1.0	2,320	0.8	540	—2.0	88
1.5	541	1.2	408	.5	1,440	1.5	3,340	1.0	770	—1.0	130
2.0	771	1.4	475	1.0	1,900	2.0	4,400	1.2	1,000	.0	280
2.5	1,081	1.6	552	1.5	2,450	2.5	5,540	1.4	1,230	1.0	600
3.0	1,320	1.8	637	2.0	3,060	3.0	6,800	1.6	1,460	2.0	1,000
3.5	1,625	2.0	727	2.5	3,760	3.5	8,260	1.8	1,690	3.0	1,470
4.0	1,970	2.2	823	3.0	4,540	4.0	9,900	2.0	1,920	4.0	2,000
4.5	2,350	2.4	924	3.5	5,340	4.5	11,615	2.4	2,380	5.0	2,555
5.0	2,660	2.6	1,030	4.0	6,300	5.0	13,380	2.8	2,840	6.0	3,110
5.5	2,915	2.8	1,140	4.5	7,275	5.5	15,045	3.2	3,300	8.0	4,220
6.0	3,125	3.0	1,250	5.0	8,250	6.0	16,760	3.6	3,760	10.0	5,330
6.5	3,300	3.2	1,365	5.5	9,225	6.5	18,475	4.0	4,220	12.0	6,440
7.0	3,430	3.4	1,485	6.0	10,200	7.0	20,190	4.5	4,795	14.0	7,550
7.5	3,575	3.6	1,615	6.5	11,175	7.5	21,905	5.0	5,370	16.0	8,660
8.0	3,720	3.8	1,745	7.0	12,150	8.0	23,620	5.5	5,945	18.0	9,770
8.5	3,865	4.0	1,875	7.5	13,125	8.5	25,335	6.0	6,520	20.0	10,880
9.0	4,010	4.2	2,005	8.0	14,100	9.0	27,050	6.5	7,095	22.0	12,500
9.5	4,155	4.4	2,135	9.0	16,050	9.5	28,965	7.0	7,670	24.0	14,700
10.0	4,300	4.6	2,275	10.0	18,000	10.0	31,200	7.5	8,245	26.0	17,600
11.0	4,590	4.8	2,420	11.0	19,950	10.5	34,062	8.0	8,820	28.0	21,500
12.0	4,880	5.0	2,585	12.0	21,900	11.0	37,600	8.5	9,395	30.0	26,500
13.0	5,170	5.2	2,765	13.0	23,850	11.5	41,200	9.0	9,970	32.0	31,700
14.0	5,460	5.4	2,955	14.0	25,800	12.0	44,800	9.5	10,545	34.0	38,000
15.0	5,750	5.6	3,140	15.0	27,750	12.5	48,400	10.0	11,120	36.0	45,000
16.0	6,040	5.8	3,335	16.0	29,700	13.0	52,000	11.0	12,270	38.0	53,000
17.0	6,330	6.0	3,525	17.0	31,650	13.5	55,600	12.0	13,420	40.0	61,000
18.0	6,620	6.2	3,715	18.0	33,600	14.0	59,200	13.0	14,570	45.0	81,000
19.0	6,910	6.4	3,910	20.0	37,500	14.5	62,800	14.0	15,720	50.0	101,000
20.0	7,200	6.6	4,110	22.0	41,400	15.0	66,400	15.0	16,870	55.0	121,000
22.0	7,780	6.8	4,330	24.0	45,300	15.5	70,000	.....	.....	.....	.....

OHIO RIVER DRAINAGE.

DESCRIPTION OF RIVER STATIONS.

Friendsville station on Youghiogheny River.—This station at Friendsville, Garrett County, Maryland, was established August 17, 1898, by E. G. Paul. The observer is J. H. Cuppet, a merchant residing within a short distance of the gage. The height of water is obtained by means of a wire attached to the floor timber on the lower side of the highway iron bridge connecting the east and west portions of the village. This wire is 20 feet long from zero to the extreme end of the weight. The scaleboard is 14 feet long, graduated to tenths of a foot. The stream channel is straight for several hundred feet above and below the bridge, and it has a solid bottom with high banks on the right-hand side.

Radford station on New River.—This is located on the New River (highway) Bridge, close by Radford Station, on the Norfolk and Western Railway. It was established August 1, 1898, by D. C. Humphreys. The observer of river heights is A. J. Killinger, Radford, Virginia. The gage used was erected by the United States Weather Bureau, and consists of a vertical board, graduated to tenths of a foot, attached to the iron framework connecting the pair of iron concrete cylinders which form the first pier from the right bank, close to the upper of the two cylinders. The bench mark is the bottom of the lowest horizontal brace, connecting the two cylinders; the elevation above the zero of the gage is 3.88 feet. The discharge measurements were made from the lower edge of the bridge, and the initial point for soundings is the right bank of the river, 40 feet from the first pier. The channel is remarkably uniform and nearly straight for about half a mile above and below the station. The bottom is of solid rock and gravel, and is smooth and regular. On the left bank there is a very narrow bottom, and then a steep rocky bluff; on the right bank the bottom, which is overflowed in extreme high water, is about 100 yards wide, but all water must go under the bridge, which is about 85 feet above low water.

Alderson station on Greenbrier River.—Described on page 58 of Paper No. 15; results for 1897 given on pages 253 and 254 of the Nineteenth Annual Report, Part IV.

Fayette station on New River.—Described on page 59 of Paper No. 15; results for the year 1897 given on pages 255–266, of the Nineteenth Annual Report, Part IV.

Asheville station on French Broad River.—Described on page 60 of Paper No. 15; results for 1897 given on pages 257–259 of the Nineteenth Annual Report, Part IV.

Bryson station on Tuckaseegee River.—Described on page 61 of Paper 15.

Judson station on Little Tennessee River.—Described on page 62 of Paper No. 15.

Murphy station on Hiwassee River.—Described on page 63 of Paper No. 15; results for 1897 given on page 259 of the Nineteenth Annual Report, Part IV.

Blueridge station on Toccoa River.—This station, at Morganton Bridge, about 4 miles east of the town of Blue Ridge, was established on November 25, 1898, and J. L. Seabolt, mail carrier from Blueridge to Morganton, Georgia, was employed as observer. He has since died, and his son, H. M. Seabolt, who is now the mail carrier, has been employed in his stead. He crosses the bridge twice every day except Sunday. No readings are had on this day, but figures have been interpolated in the list. The gage is a 14-foot rod in two 7-foot sections, nailed to a tree on the right bank just below the bridge. It is graduated to feet and tenths, and is set to conform to bench marks which were established October 15, 1896, and August 26, 1898. The measurement in 1896 was made at the railroad bridge, about 3 miles below, but is referred to the present gage by comparison of bench marks at the two bridges on August 26, 1898. The bench mark at Morganton Bridge is on the top of the bridge floor on the downstream side, 50 feet from the initial point, and is 18 feet above zero of gage. Morganton Bridge is a wooden, queen-bolt open bridge in three spans, with a total length between abutments of 153 feet. The width of the river, including two piers, at ordinary stage, is 143 feet between the banks, the three channels being 50, 38, and 33 feet, respectively.

Chattanooga station on Tennessee River.—Described on page 64 of Paper No. 15; results for 1897 given on pages 260 to 262 of the Nineteenth Annual Report, Part IV.

Columbus station on Olentangy River.—This station, established on November 22, 1898, by H. A. Pressey, Prof. C. N. Brown, and B. H. Flynn is located at the Fifth Avenue Bridge, in Columbus, Ohio. The gagings are made from the downstream side of the bridge, the initial point being on the left bank. The gage is a wooden post, graduated to feet and tenths, driven in the bed of the stream near the bridge. The gage rod is referred to a scale cut in the face of the left abutment, from which the high-water readings can be taken directly. The bed is rocky and the banks high and never overflowed. This is the only available section at Columbus on this river at which the banks are not overflowed at high water. The observer is Prof. C. N. Brown, University of Ohio, Columbus.

Columbus station on Scioto River.—This station, established on November 22, 1898, by H. A. Pressey, Prof. C. N. Brown, and B. H. Flynn is located at the Grand View Avenue Bridge, in Columbus, Ohio. The wire gage is on the upstream side of the bridge and is referred to a scale cut in the face of the left abutment, from which high-water reading can be taken directly. The bed is rocky and the banks seldom overflow. The observer is A. T. Scurman, Columbus, Ohio.

TABLES OF DAILY GAGE HEIGHT.

Daily gage height, in feet, of Youghiogheny River at Friendsville, Maryland, for 1898.

Day.	Aug.	Sept.	Oct.	Nov.	Dec.	Day.	Aug.	Sept.	Oct.	Nov.	Dec.
1	.....	4.20	4.00	4.90	4.90	17	4.90	4.00	4.20	5.20	5.20
2	.....	4.10	4.00	4.90	4.90	18	4.80	4.00	4.40	5.20	5.10
3	.....	4.10	4.00	4.80	4.80	19	4.70	4.00	4.40	5.20	5.10
4	.....	4.10	4.00	4.70	4.70	20	5.90	4.00	4.90	5.70	6.10
5	.....	4.10	4.00	4.70	4.70	21	5.20	4.00	4.70	5.60	7.50
6	.....	4.30	4.10	4.80	4.70	22	4.90	4.00	7.90	5.40	7.60
7	.....	4.40	4.20	4.70	4.70	23	4.70	4.00	7.00	5.40	7.70
8	.....	4.50	4.20	4.90	4.70	24	4.60	4.40	6.10	5.20	7.10
9	.....	4.40	4.20	5.10	4.70	25	4.60	4.30	5.60	5.10	6.50
10	.....	4.40	4.10	5.10	4.80	26	4.50	4.30	5.60	5.00	5.60
11	.....	4.10	4.10	6.30	4.90	27	4.50	4.20	5.50	4.80	5.60
12	.....	4.00	4.10	5.90	5.10	28	4.40	4.00	5.30	4.90	5.60
13	.....	4.00	4.10	5.70	5.10	29	4.30	4.00	5.10	4.80	5.40
14	.....	4.00	4.20	5.50	5.10	30	4.20	4.00	5.00	4.80	5.30
15	.....	4.00	4.20	5.40	5.20	31	4.20	.....	5.00	.....	5.20
16	.....	4.00	4.30	5.30	5.20						

Daily gage height, in feet, of New River at Radford, Virginia, for 1898.

Day.	Aug.	Sept.	Oct.	Nov.	Dec.	Day.	Aug.	Sept.	Oct.	Nov.	Dec.
1	0.90	0.60	0.50	1.00	0.80	17	0.50	0.50	0.80	0.90	0.90
2	.50	.50	.60	.90	.70	18	.60	.40	.90	1.00	.80
3	.40	.50	.70	1.00	.90	19	.50	.40	6.60	1.20	1.20
4	.50	2.00	.80	.90	.80	20	.80	.30	2.90	1.20	1.00
5	3.40	3.90	3.90	.80	2.60	21	.80	.20	2.00	1.00	1.20
6	1.30	1.80	3.85	.90	2.00	22	.90	.30	9.90	1.10	1.30
7	1.50	1.00	3.00	.80	1.90	23	.80	6.30	4.00	1.00	1.50
8	1.00	.80	1.80	1.00	1.80	24	.60	5.80	2.90	.90	1.90
9	.90	.70	.90	.70	1.30	25	.50	1.80	2.00	.80	1.30
10	1.00	.60	.80	.60	1.20	26	.80	1.00	1.90	.90	1.20
11	1.40	.50	1.00	.60	1.10	27	.90	.90	1.80	.80	.90
12	1.90	.50	.90	.90	1.10	28	1.00	.80	1.60	.90	.80
13	1.80	.40	.80	.80	.90	29	.90	.70	1.20	.80	.70
14	1.80	.60	.60	.70	.80	30	.80	.60	1.60	.70	.80
15	1.00	.70	.50	.60	.90	31	.60	.....	1.50	.....	.90
16	.70	.60	.60	.50	1.00						

Daily gage height, in feet, of Greenbrier River at Alderson, West Virginia, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	2.32	2.82	2.62	5.40	2.85	2.63	1.95	2.20	1.85	1.62	2.60	2.67
2	2.35	2.42	2.58	4.50	2.70	2.50	1.87	2.65	1.85	1.62	2.60	2.63
3	2.77	2.27	2.54	4.10	2.60	2.38	1.81	2.25	1.63	1.57	2.55	2.43
4	2.20	2.40	2.52	3.73	2.55	2.30	1.78	2.20	1.75	1.57	2.40	2.37
5	2.12	2.79	2.50	3.48	2.48	2.20	2.00	6.15	1.68	1.58	2.38	3.25
6	2.15	2.42	2.54	3.53	3.03	2.15	2.35	5.35	1.75	1.60	2.34	3.95
7	2.18	2.41	2.55	3.40	8.03	2.07	2.10	5.35	1.80	1.86	2.34	3.35
8	2.17	2.50	2.55	3.30	7.33	2.02	2.06	3.67	2.00	1.78	2.42	3.05
9	2.19	2.40	2.60	3.30	5.20	1.98	1.95	3.10	1.90	1.70	2.37	2.78
10	3.58	2.50	2.65	3.25	4.23	1.95	1.87	3.08	1.85	1.70	2.30	2.72
11	6.95	2.85	2.60	3.95	3.20	1.90	1.82	7.90	1.80	1.70	2.40	3.00
12	4.90	3.15	2.63	7.08	3.45	2.33	1.70	15.50	1.75	1.72	3.88	2.37
13	4.20	3.65	2.70	5.33	3.17	2.13	1.63	5.56	1.70	1.70	3.40	2.50
14	4.00	3.45	2.75	4.65	3.00	2.02	1.73	4.28	1.65	1.70	3.05	2.55
15	3.60	3.22	2.77	4.57	2.85	2.55	1.70	3.55	1.65	1.70	2.90	2.67
16	7.85	3.05	2.68	4.50	2.90	2.45	1.79	3.15	1.68	1.65	2.72	2.48
17	5.45	2.87	2.67	5.00	2.95	2.38	1.88	2.85	1.63	1.65	2.60	2.13
18	4.20	2.70	5.25	4.30	3.34	2.40	1.90	2.65	1.58	1.65	2.68	2.25
19	3.60	2.80	5.93	3.80	3.20	2.36	2.47	2.50	1.58	2.28	4.60	2.25
20	3.25	3.65	5.15	3.40	3.10	2.55	2.35	2.55	1.58	2.58	6.15	2.42
21	3.28	4.05	4.20	3.20	2.95	2.60	2.20	2.65	1.58	2.93	5.15	2.73
22	3.37	4.65	3.67	3.00	2.82	2.45	2.08	2.50	1.60	9.83	4.22	3.45
23	3.67	3.93	3.40	2.90	5.04	2.40	1.94	2.35	1.65	6.60	3.80	5.70
24	4.60	3.45	3.25	2.80	5.50	2.15	2.05	2.20	1.70	4.30	3.92	5.66
25	4.00	3.18	5.32	3.36	4.60	2.03	2.27	2.25	1.80	3.43	3.60	4.40
26	4.00	2.98	5.28	3.40	3.85	1.98	2.05	2.15	1.82	3.03	3.27	3.70
27	3.98	2.83	4.43	3.43	3.38	1.92	2.08	2.05	1.76	3.02	3.08	3.32
28	3.62	2.68	3.85	3.80	3.05	1.93	3.51	2.05	1.73	2.62	2.88	3.05
29	3.30	.....	4.19	3.15	2.90	2.10	3.38	2.00	1.70	2.60	2.68	2.90
30	3.13	.....	7.95	3.00	2.75	2.02	2.80	1.95	1.68	2.50	2.68	2.73
31	2.90	.....	6.40	.....	2.75	.....	2.45	1.90	.....	2.58	.....	2.70

Daily gage height, in feet, of New River at Fayette, West Virginia, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	2.40	4.00	2.95	15.43	4.10	4.20	1.30	4.50	2.45	2.20	4.25	5.05
2	2.20	3.30	2.80	11.70	3.85	3.50	1.22	4.50	2.20	2.10	4.20	4.50
3	2.20	2.70	2.65	8.90	3.40	3.10	1.15	4.10	1.95	2.05	4.25	4.20
4	2.15	2.00	2.65	8.00	3.00	2.60	1.07	4.20	1.80	1.80	4.30	4.15
5	2.10	1.55	2.65	7.40	2.85	2.10	1.40	9.55	2.10	1.75	2.50	4.05
6	2.25	1.50	2.68	7.30	3.00	2.05	1.30	12.85	8.20	6.18	2.55	7.40
7	2.40	1.55	2.80	6.80	9.45	1.90	1.35	9.65	5.00	8.20	4.05	6.25
8	2.70	1.50	2.85	7.65	14.95	1.50	1.40	7.10	3.95	6.55	3.90	6.35
9	2.80	1.50	2.95	6.10	10.80	1.35	1.65	7.05	3.65	4.20	3.95	5.00
10	3.60	1.40	2.90	6.05	7.40	1.15	1.60	13.05	3.20	3.55	4.10	4.05
11	4.55	3.10	2.75	6.80	6.10	1.15	1.50	19.15	2.20	3.50	4.05	3.30
12	6.40	4.20	2.70	10.85	5.55	1.50	1.45	16.10	2.40	3.35	3.95	3.40
13	6.80	5.40	2.65	9.80	4.95	1.50	1.40	10.85	2.20	3.10	3.80	3.45
14	5.85	4.85	2.60	8.40	4.55	1.40	1.30	9.05	1.95	3.00	3.90	3.45
15	5.60	4.80	2.80	8.35	4.25	1.30	1.25	8.00	1.65	2.65	3.90	3.40
16	7.40	3.70	3.05	10.30	4.30	1.35	1.20	6.80	1.55	2.60	3.55	3.40
17	10.00	3.20	3.60	8.15	4.58	1.48	1.15	5.55	1.30	2.40	3.50	3.35
18	7.05	3.00	4.00	6.80	4.50	2.50	1.00	4.80	1.30	2.30	3.35	3.30
19	6.80	2.85	8.55	6.00	4.45	5.40	3.00	4.35	1.30	2.25	3.45	4.35
20	6.10	3.10	8.30	5.70	4.30	8.10	3.20	4.25	1.20	12.05	5.75	6.50
21	4.25	5.45	6.70	5.30	3.95	6.30	3.45	4.05	1.15	11.70	8.10	8.10
22	5.85	6.15	6.00	5.00	3.80	6.00	2.15	4.00	1.20	14.10	7.40	7.20
23	6.10	5.70	6.80	4.80	11.40	4.80	2.05	3.40	1.20	21.25	5.50	7.45
24	6.70	5.10	7.35	4.50	13.90	3.25	2.00	3.20	8.43	14.40	5.55	9.00
25	8.10	4.40	8.60	4.55	11.25	2.55	2.48	2.95	9.35	9.00	5.60	6.55
26	7.35	3.65	10.15	5.10	9.10	2.20	5.15	2.60	8.10	6.55	6.10	6.10
27	8.90	3.40	10.05	5.15	7.00	1.95	4.80	2.45	7.00	5.10	4.80	5.25
28	8.60	3.10	7.25	5.05	5.95	1.60	4.45	2.20	5.30	4.15	4.65	4.10
29	6.95	.....	10.00	4.60	5.45	1.55	4.60	3.15	4.60	3.40	4.60	4.00
30	5.40	.....	13.90	4.35	5.40	1.40	4.65	3.30	2.70	3.30	4.45	3.65
31	5.05	.....	17.85	.....	4.80	.....	4.60	3.20	.....	3.30	.....	5.10

Daily gage height, in feet, of French Broad River at Asheville, North Carolina, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	3.25	3.52	2.77	4.60	3.30	2.70	2.55	3.70	3.60	3.45	3.50	3.60
2	3.25	3.47	2.75	4.05	3.30	2.67	2.35	3.90	3.50	3.33	3.60	3.55
3	3.15	3.45	2.73	4.05	3.27	2.63	2.85	4.10	3.45	5.25	3.50	3.30
4	3.03	3.35	2.70	4.10	3.25	2.63	2.63	8.55	6.33	8.10	3.43	3.25
5	2.87	3.15	2.70	4.20	3.17	2.60	2.60	7.23	6.00	7.50	3.40	3.30
6	2.93	3.10	2.70	4.23	3.10	2.60	2.60	6.40	5.75	6.75	3.35	3.35
7	2.90	3.05	2.65	4.10	3.03	2.55	2.55	5.77	5.90	7.03	3.03	3.40
8	2.90	3.00	2.63	3.80	3.03	2.55	2.55	5.60	5.00	6.05	3.25	3.35
9	2.80	3.00	2.63	3.40	3.00	2.55	2.55	5.00	4.65	6.00	3.02	3.25
10	2.80	2.90	2.60	3.40	3.00	2.53	3.40	4.40	4.30	5.60	3.15	3.20
11	2.90	2.85	2.60	3.40	2.90	2.50	2.85	6.60	4.25	5.40	3.01	3.15
12	3.00	2.80	2.60	3.37	4.00	2.50	2.80	7.20	3.95	4.70	3.01	3.13
13	3.00	2.85	2.63	3.25	4.00	2.60	4.95	6.95	3.90	3.80	3.10	3.10
14	2.93	2.77	2.60	3.27	3.40	2.65	7.00	6.50	3.80	3.80	3.50	3.00
15	2.90	2.73	2.60	3.25	3.30	2.70	6.65	6.00	3.75	3.80	3.10	2.97
16	2.85	2.75	2.90	3.25	3.05	2.90	6.50	5.00	3.65	3.60	3.15	2.95
17	2.85	2.75	2.75	3.23	3.00	3.00	6.50	4.40	3.57	3.80	3.20	2.90
18	2.77	3.00	2.73	3.20	2.95	3.35	6.00	4.40	3.55	6.30	3.30	2.93
19	3.20	3.15	2.70	3.17	2.95	4.50	5.00	4.40	3.50	6.20	3.20	3.10
20	3.30	3.10	2.70	3.15	2.93	4.50	3.85	4.37	3.45	6.10	3.20	3.25
21	4.20	3.07	2.85	2.97	2.90	4.00	4.10	4.35	3.40	6.10	3.25	3.30
22	4.30	3.05	2.85	2.95	2.90	3.90	5.30	4.30	3.40	7.00	3.27	4.80
23	4.30	2.95	2.88	3.95	3.10	3.55	5.20	4.23	7.30	6.50	3.23	5.50
24	4.40	2.90	2.80	3.90	3.05	2.70	4.90	4.15	6.60	5.00	3.30	5.00
25	4.50	2.80	2.77	3.90	2.90	2.55	4.50	4.08	5.70	4.10	3.25	4.90
26	5.30	2.80	2.73	4.27	2.80	2.50	4.20	4.00	4.90	4.00	3.25	4.50
27	4.00	2.83	2.71	4.25	2.70	2.60	4.00	3.90	3.85	4.00	3.20	4.00
28	3.75	2.80	2.70	4.20	2.75	3.20	3.80	3.80	3.80	3.85	3.30	5.50
29	3.65	.....	5.00	3.70	2.75	3.15	3.70	3.73	3.70	3.30	3.40	5.20
30	3.60	.....	6.00	3.30	2.75	3.12	3.60	3.70	3.50	3.33	3.53	5.10
31	3.55	.....	5.70	.....	2.73	.....	3.53	3.70	.....	3.30	.....	4.70

Daily gage height, in feet, of Tuckaseegee River at Bryson, North Carolina, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	1.50	1.80	1.50	3.10	2.00	1.50	1.40	2.80	2.00	1.85	2.00	2.20
2	1.20	1.75	1.40	2.80	1.90	1.40	1.35	2.40	3.10	1.70	1.95	2.15
3	1.30	1.75	1.40	2.60	1.85	1.35	1.30	2.50	8.50	1.70	1.90	2.00
4	1.40	1.85	1.40	2.50	1.80	1.35	1.40	7.80	4.50	7.60	1.80	2.70
5	1.40	1.70	1.35	2.80	2.00	1.30	1.50	4.10	6.00	5.70	1.80	2.50
6	1.35	1.60	1.35	2.50	1.90	1.30	1.55	3.50	3.80	4.30	1.95	2.25
7	1.50	1.65	1.35	2.50	1.85	1.30	1.60	2.80	3.60	3.60	1.90	2.20
8	1.40	1.60	1.35	2.40	1.85	1.30	1.60	2.60	3.50	3.20	1.90	2.00
9	1.50	1.60	1.30	2.25	1.80	1.30	1.50	2.50	3.25	2.90	2.15	2.00
10	1.60	1.60	1.30	2.65	1.80	1.30	1.40	2.30	2.70	2.80	2.50	1.90
11	1.60	1.55	1.30	2.40	1.80	1.25	1.30	5.30	2.50	2.80	2.00	1.80
12	2.25	1.65	1.35	2.25	1.80	1.40	1.30	3.50	2.30	2.90	2.00	1.80
13	2.25	1.55	1.60	2.20	1.75	1.40	1.30	3.20	2.10	2.40	2.00	1.75
14	2.00	1.55	1.60	2.40	1.60	1.40	3.50	3.00	2.10	2.30	2.00	1.60
15	1.90	1.45	1.70	2.30	1.60	1.30	2.00	2.90	2.00	2.25	1.90	1.70
16	2.10	1.40	1.65	2.25	2.00	1.50	2.00	2.50	2.00	2.25	2.00	1.70
17	1.90	1.40	1.70	2.15	1.60	1.90	1.70	2.40	2.00	5.80	2.10	1.90
18	1.75	1.50	2.10	2.10	1.60	1.70	1.70	2.50	1.90	3.40	2.50	1.80
19	2.20	1.60	1.90	2.20	2.00	1.70	1.50	2.30	1.90	2.80	2.50	1.80
20	3.50	1.60	1.70	2.10	1.90	1.60	1.40	2.30	1.85	2.80	2.40	2.25
21	2.50	1.55	1.60	2.00	1.60	1.40	1.50	2.20	1.70	2.70	2.20	2.20
22	2.20	1.50	1.50	1.95	1.60	1.30	1.55	2.10	4.30	2.55	2.50	2.00
23	2.60	1.40	1.50	2.10	1.80	1.30	1.60	2.00	3.30	2.45	2.40	1.90
24	2.80	1.45	1.70	2.05	1.80	1.35	1.60	2.10	2.80	2.45	2.25	2.35
25	4.50	1.40	1.50	2.50	1.55	1.40	1.90	2.00	2.30	2.20	2.40	2.35
26	3.80	1.40	1.50	2.40	1.55	1.30	1.90	1.90	2.00	2.30	2.20	2.50
27	2.70	1.40	1.60	2.40	1.50	1.30	2.10	1.90	1.90	2.15	2.00	2.25
28	2.50	1.35	1.70	2.20	1.50	1.40	2.40	1.80	1.90	2.10	2.00	2.90
29	2.20	.....	6.70	2.10	1.50	1.35	2.00	1.75	1.85	2.05	2.40	2.80
30	2.10	.....	5.50	2.00	1.50	1.30	2.00	2.00	1.85	2.10	2.25	2.80
31	2.00	.....	3.80	.....	1.50	.....	2.20	2.20	.....	2.00	.....	2.60

Daily gage height, in feet, of Little Tennessee River at Judson, North Carolina, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	2.83	2.57	2.92	5.78	3.42	2.41	2.71	3.85	5.28	3.53	4.58	3.89
2	2.90	2.90	2.80	5.60	3.63	2.42	2.18	3.42	7.22	3.56	4.52	3.89
3	2.73	2.84	2.90	4.32	3.62	2.42	2.19	4.21	11.96	3.82	4.53	3.88
4	2.75	2.93	2.73	3.38	3.60	2.38	2.17	10.38	9.52	8.71	4.53	3.88
5	2.76	2.56	3.00	5.50	3.68	2.39	2.16	5.72	7.21	13.50	4.59	3.81
6	2.70	2.80	2.98	4.58	3.61	2.30	2.13	4.98	6.82	10.22	4.57	3.80
7	2.80	2.59	2.74	3.96	4.23	2.37	2.20	4.52	5.91	8.28	4.58	3.74
8	2.73	2.56	2.78	3.85	3.56	2.36	2.21	4.31	4.51	6.71	4.51	3.74
9	2.71	2.58	2.37	3.38	3.58	2.36	2.20	4.28	4.28	5.89	4.52	3.71
10	2.70	2.38	2.30	3.40	3.53	2.38	2.15	5.78	3.91	5.82	3.96	3.72
11	2.68	2.30	2.34	3.00	3.98	2.37	2.16	7.91	3.92	4.20	3.98	3.70
12	2.89	2.36	2.36	3.56	3.98	2.39	2.78	8.53	3.81	4.00	3.97	3.69
13	2.73	2.60	2.39	3.58	3.70	2.20	3.00	9.02	3.59	3.52	3.98	3.68
14	2.78	2.74	2.40	3.59	3.69	2.33	3.98	8.93	3.58	3.58	3.91	3.68
15	2.76	2.73	2.98	3.52	3.68	2.30	6.81	5.58	3.58	3.54	3.92	3.67
16	2.79	2.76	2.96	3.90	3.62	2.72	4.20	4.98	3.52	3.48	3.92	3.64
17	2.78	2.80	2.96	3.46	3.67	2.71	3.28	4.92	3.49	3.44	3.90	3.63
18	3.00	3.00	3.48	3.40	3.49	2.78	3.00	4.71	3.44	6.95	3.88	3.60
19	3.56	3.11	3.00	3.49	3.51	2.70	2.78	4.83	3.43	4.53	3.87	3.58
20	3.58	3.23	2.98	3.92	3.56	2.62	2.71	4.38	3.48	4.52	3.89	3.59
21	3.59	3.28	2.90	3.90	3.00	2.63	2.68	4.78	3.49	3.98	3.89	3.59
22	4.42	3.00	2.92	3.58	3.90	2.60	2.41	4.91	3.47	3.91	3.88	3.57
23	4.40	3.00	2.93	3.98	3.72	2.70	3.52	4.58	3.42	3.91	3.86	3.57
24	3.58	2.90	2.90	3.52	3.45	2.71	3.21	4.53	3.48	3.84	3.86	4.98
25	3.50	2.29	2.97	3.54	3.42	2.74	3.00	4.51	3.47	3.98	3.84	3.59
26	3.48	2.70	2.97	3.50	3.44	2.70	3.21	4.51	3.46	4.41	3.83	3.57
27	5.58	2.78	2.56	3.28	3.37	2.73	3.58	4.52	3.44	4.52	3.85	3.58
28	5.20	2.78	3.04	3.29	3.33	2.70	3.28	4.53	3.45	4.57	3.88	3.56
29	3.39	.....	8.30	3.24	3.30	2.78	3.29	4.38	3.48	4.61	3.89	3.52
30	3.86	.....	7.79	3.40	2.27	2.79	3.22	4.38	3.52	4.52	3.88	3.53
31	2.94	.....	6.39	.....	2.30	.....	3.30	4.59	.....	4.58	.....	3.50

Daily gage height, in feet, of Hiwassee River at Murphy, North Carolina, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	5.30	5.60	5.22	7.00	5.80	5.12	4.95	5.82	5.40	5.60	5.85	6.00
2	5.20	5.45	5.20	6.50	5.80	5.12	4.95	5.60	12.05	5.60	5.85	5.90
3	5.10	5.62	5.32	6.21	5.70	5.10	4.90	5.82	13.97	5.50	5.80	5.85
4	5.30	5.50	5.30	6.10	5.65	5.10	4.90	9.80	10.10	14.40	5.80	5.90
5	5.25	5.50	5.21	8.75	5.65	5.10	5.50	9.35	9.75	11.60	5.80	6.10
6	5.30	5.42	5.20	7.00	5.51	5.20	5.20	6.75	7.50	8.30	6.10	6 10
7	5.30	5.40	5.20	6.55	5.60	5.10	5.10	6.50	7.10	7.30	5.85	6.10
8	5.30	5.40	5.20	6.30	5.60	5.10	5.31	7.02	6.85	7.00	5.80	6.00
9	5.20	5.40	5.20	6.11	5.60	5.10	5.10	6.80	6.60	6.70	5.80	5.95
10	5.25	5.40	5.20	6.05	5.50	5.10	5.30	8.30	6.60	6.50	5.72	5.90
11	5.30	5.40	5.20	6.10	5.50	5.05	5.10	10.00	6.30	6.40	5.90	5.90
12	6.00	5.30	5.20	6.00	5.50	5.00	5.00	7.50	6.20	6.32	5.85	5.85
13	5.85	5.30	5.20	5.90	5.40	5.00	4.91	7.15	6.12	6.20	5.80	5.80
14	5.80	5.30	5.30	5.95	5.40	5.01	5.90	6.81	6.05	6.20	5.90	5.75
15	5.60	5.30	5.35	5.95	5.40	5.10	6.12	6.40	6.00	6.05	5.85	5.70
16	5.80	5.25	5.32	5.85	5.50	5.15	5.70	6.20	5.90	6.00	5.85	5.70
17	5.70	5.25	5.40	5.81	5.40	5.50	5.50	6.20	6.00	6.00	5.85	5.70
18	5.60	5.22	5.40	5.80	5.40	5.45	5.30	6.30	5.80	9.20	6.00	5.70
19	5.60	5.30	5.40	5.75	5.35	5.20	5.21	6.25	5.70	6.70	6.70	5.70
20	5.90	5.25	5.40	5.85	5.30	5.15	5.15	6.10	5.70	6.40	6.40	6.00
21	6.10	5.35	5.36	5.70	5.30	5.10	5.01	6.10	5.65	6.23	6.20	5.70
22	5.90	5.30	5.35	5.70	5.30	5.10	5.30	5.90	5.70	6.30	6.10	5.70
23	6.00	5.30	5.30	5.65	5.35	5.05	5.40	5.75	6.05	6.20	6.50	6.10
24	5.78	5.27	5.25	6.20	5.60	5.02	5.60	5.70	5.80	6.10	6.25	6.00
25	7.75	5.30	5.40	6.10	5.32	5.05	6.00	5.65	5.70	6.10	6.10	5.90
26	7.20	5.22	5.40	5.95	5.25	5.00	5.90	5.80	5.70	6.10	6.10	5.80
27	6.50	5.22	5.30	6.20	5.25	5.05	5.60	5.70	5.65	6.05	6.00	5.80
28	6.18	5.25	5.30	6.10	5.21	5.01	6.20	5.70	5.60	6.00	6.00	5.75
29	6.00	.....	11.10	6.00	5.20	5.00	5.80	5.60	5.60	6.00	6.20	5.70
30	5.82	.....	9.40	5.90	5.20	4.95	5.65	5.60	5.60	5.95	6.00	5.70
31	5.71	.....	7.70	.....	5.10	.....	6.20	5.60	.....	5.90	.....	5.90

Daily gage height, in feet, of Toccoa River at Blueridge, Georgia, for 1898.

Day.	Nov.	Dec.	Day.	Nov.	Dec.	Day.	Nov.	Dec.	Day.	Nov.	Dec.
1	.....	3.10	9	.....	3.10	17	.....	2.80	25	3.15	3.00
2	.....	3.00	10	.....	3.00	18	.....	2.70	26	3.20	2.80
3	.....	3.00	11	.....	2.90	19	.....	2.50	27	3.40	2.80
4	.....	3.20	12	.....	2.80	20	.....	3.10	28	3.40	2.90
5	.....	3.40	13	.....	2.80	21	.....	3.00	29	3.40	2.90
6	.....	3.40	14	.....	2.80	22	.....	2.80	30	3.40	2.80
7	.....	3.10	15	.....	2.80	23	.....	2.40	31	.....	3.20
8	.....	3.00	16	.....	2.80	24	.....	3.10			

Daily gage height, in feet, of Tennessee River at Chattanooga, Tennessee, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	3.45	7.55	3.30	17.45	6.40	3.35	2.45	8.15	3.55	3.55	4.60	5.10
2	3.25	6.70	3.15	17.80	5.80	3.30	2.35	7.55	3.95	3.80	4.30	5.05
3	3.05	6.15	3.00	15.00	5.40	3.30	2.25	6.45	9.15	3.20	4.25	4.90
4	2.90	5.40	2.95	11.45	5.05	3.30	2.05	5.35	18.50	3.90	4.05	5.00
5	2.75	5.00	3.30	10.35	4.70	2.85	2.35	6.25	25.00	8.90	3.90	5.05
6	2.65	4.55	3.45	12.15	4.45	2.55	2.10	11.85	22.15	16.90	3.90	5.60
7	2.70	4.45	3.50	11.60	4.35	2.35	2.10	14.65	15.70	16.50	4.25	5.95
8	2.80	4.35	3.40	10.30	4.10	2.20	2.15	12.55	11.25	10.75	4.45	5.90
9	3.05	4.30	3.25	9.30	4.20	2.05	2.60	10.15	9.50	8.80	4.50	5.85
10	3.25	4.15	3.05	8.30	4.15	1.95	3.05	8.50	8.60	8.40	4.45	5.55
11	3.25	4.00	2.90	8.60	4.45	1.80	3.50	9.05	7.45	7.55	4.65	5.10
12	5.50	3.90	2.85	9.50	4.65	1.95	3.40	12.30	6.45	6.55	5.05	4.75
13	13.20	3.80	2 80	9.40	4.40	1.80	3.20	14.85	5.70	6.00	5.30	4.55
14	14.40	3.80	2.85	9.00	4.15	1.75	2.80	15.85	5.20	5.70	4.95	4.30
15	12.25	3.80	3.15	9.05	3.95	1.65	2.85	14.95	4.80	5.35	4.55	4.00
16	12.20	3.70	5.10	9.15	3.90	1.75	3.50	11.60	4.45	4.90	4.40	3.85
17	12.35	3.55	5.05	8.60	3.80	2.00	4.55	8.90	4.25	4.70	4.55	3.70
18	10.00	3.50	5.20	8.20	3.70	2.35	5.35	7.10	3.95	5.25	4.75	3.60
19	9.20	3.30	5.50	8.00	3.70	3.50	4.60	6.40	3.75	6.70	4.95	3.75
20	11.70	3.30	6.10	7.95	3.65	4.05	4.15	6.05	3.55	7.75	5.30	5.20
21	13.80	3.20	5.70	7.40	3.60	5.35	4.00	5.95	3.45	9.30	5.85	5.85
22	13.40	3.25	5.45	7.05	3.60	5.55	3.30	5.65	3.55	8.80	6.05	6.00
23	12.55	3.40	5.15	6.60	3.50	5.05	3.30	5.40	5.00	7.65	6.55	5.85
24	12.35	3.50	4.65	6.85	3.40	4.55	3.40	4.75	5.05	7.25	6.85	5.35
25	12.35	3.60	4.30	6.65	3.45	3.70	3.55	4.30	6.40	7.20	6.55	5.20
26	16.05	3.80	4.15	6.60	3.70	3.40	3.55	4.05	7.20	7.60	6.19	5.40
27	18.20	3.50	4.45	6.45	4.95	2.90	4.55	4.00	6.15	6.90	5.65	5.90
28	16.70	3.35	4.45	7.10	5.60	2.80	5.55	4.10	5.00	6.20	5.15	5.70
29	14.15	.....	4.65	7.05	4.90	2.80	5.35	4.30	4.30	5.65	4.80	5.15
30	11.20	.....	5.55	6.75	4.20	2.55	5.90	4.10	3.85	5.15	4.95	4.80
31	8.95	.....	13.25	.....	3.70	.....	7.90	3.85	.....	4.85	.....	4.50

Daily gage height, in feet, of Olentangy River at Columbus, Ohio, for 1898.

Day.	Nov.	Dec.	Day.	Nov.	Dec.	Day.	Nov.	Dec.	Day.	Nov.	Dec.
1	.....	1.30	9	.....	1.56	17	.....	1.20	25	1.34	2.45
2	.....	1.25	10	.....	1.80	18	.....	1.17	26	1.31	2.10
3	.....	1.20	11	.....	1.75	19	.....	1.18	27	1.32	1.88
4	.....	1.28	12	.....	1.40	20	.....	2.38	28	1.25	1.70
5	.....	1.62	13	.....	1.50	21	.....	6.20	29	1.20	1.65
6	.....	1.75	14	.....	1.55	22	.....	5.20	30	1.25	1.73
7	.....	1.80	15	.....	1.41	23	1.43	4.50	31	.....	2.40
8	.....	1.70	16	.....	1.40	24	1.41	3.00			

Daily gage height, in feet, of Scioto River at Columbus, Ohio, for 1898.

Day.	Nov.	Dec.	Day.	Nov.	Dec.	Day.	Nov.	Dec.	Day.	Nov.	Dec.
1	.....	9.70	9	.....	9.75	17	.....	9.30	25	9.90	13.65
2	.....	9.65	10	.....	9.75	18	.....	9.25	26	9.80	12.65
3	.....	9.70	11	.....	10.00	19	.....	9.45	27	9.85	12.10
4	.....	9.75	12	.....	9.45	20	.....	11.75	28	9.65	11.30
5	.....	9.90	13	.....	9.40	21	.....	15.10	29	9.75	11.05
6	.....	9.90	14	.....	9.55	22	10.20	16.65	30	9.80	11.15
7	.....	9.80	15	.....	9.20	23	10.05	15.65	31	.....	11.75
8	.....	9.95	16	.....	9.25	24	9.95	14.70			

List of discharge measurements.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
				Feet.	*Sec.-feet.*
1898.					
May 12	Youghiogheny River.	Friendsville, Md	E. G. Paul	4.90	571
Aug. 17	do	do	do	4.90	581
July 21	New River	Radford, Va	D. C. Humphreys	0.20	1,812
July 29	do	do	do	1.26	3,814
June 20	Greenbrier River	Alderson, W. Va	do	2.02	403
Aug. 3	do	do	do	2.20	665
Aug. 5	do	do	do	4.43	5,124
Dec. 22	do	do	do	3.45	2,817
June 25	New River	Fayette, W. Va	do	2.60	3,492
Aug. 5	do	do	do	9.15	19,027
Do.	do	do	do	10.06	21,149
Aug. 6	do	do	do	13.02	31,533
Do.	do	do	do	12.95	a 32,128
Dec. 22	do	do	do	5.94	10,902
Jan. 18	French Broad River.	Asheville, N. C	E. W. Myers	2.75	918
Sept. 9	do	do	do	4.45	3,382
Jan. 19	Tuckasegee River	Bryson, N. C	do	2.20	2,175
Jan. 20	do	do	do	3.30	3,695
Sept. 3	do	do	do	6.93	18,959
Sept. 4	do	do	do	3.93	6,059
Sept. 5	do	do	do	4.50	9,086
Do.	do	do	do	5.00	11,777
Sept. 6	Tennessee River	Judson, N. C	do	7.30	9,821
Jan. 21	Hiwassee River	Murphy, N. C	do	6.05	1,170
Sept. 8	do	do	do	6.80	1,620
1896.					
Oct. 15	Toccoa River	Blueridge, Ga	B. M. Hall	2.00	148
1898.					
Aug. 26	do	do	do	2.95	624
Nov. 25	do	do	do	3.15	797
May 10	Tennessee River	Chattanooga, Tenn	Max Hall	4.14	22,066
July 29	do	do	do	5.30	29,693
Aug. 19	do	do	do	6.37	36,671
Oct. 6	do	do	J. C. Conn	17.60	120,359
Oct. 28	do	do	do	6.00	35,953
Nov. 29	do	do	do	4.75	29,560
Do.	do	do	do	4.70	31,340
Nov. 30	Olentangy River	Columbus, Ohio	C. N. Brown	1.20	77

a Approximate.

List of miscellaneous discharge measurements, 1898.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
				Feet.	*Sec.-feet.*
Nov. 15	Youghiogheny River.	Connellsville, Pa.	E. G. Paul		1,858
Nov. 16	do	Confluence, Pa.	do		1,745
Do.	Cassellman River	do	do		699
Do.	Laurel Hill Creek	do	do		225
July 20	Tinker Creek	Roanoke, Va.	D. C. Humphreys	0.95	39
July 22	North Fork Holston River.	Saltville, Va.	do		69
July 23	Middle Fork Holston River.	Osceola, Va.	do	.30	124
Do.	South Fork Holston River.	Drowning Ford, near Abingdon, Va.	do		206
July 25	Clinch River	Speers Ferry, Va.	do	.40	680
Aug. 26	Toccoa River	Near Mineral Bluff, Ga.	B. M. Hall		628

Rating tables.

Asheville.		Bryson.		Judson.		Murphy.		Blueridge.		Chattanooga.	
Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Sec.-ft*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*
2.0	620	1.0	168	2.0	225	4.6	225	2.00	148	0.5	5,900
2.1	633	1.2	400	2.2	300	4.7	250	2.05	154	1.0	7,750
2.2	645	1.4	670	2.4	445	4.8	280	2.10	160	1.5	9,650
2.3	665	1.6	950	2.6	610	4.9	315	2.15	169	2.0	11,650
2.4	685	1.8	1,250	2.8	805	5.0	350	2.20	178	2.5	13,700
2.5	715	2.0	1,550	3.0	1,060	5.1	400	2.25	191	3.0	15,920
2.6	745	2.2	1,870	3.2	1,360	5.2	450	2.30	204	3.5	18,460
2.7	782	2.4	2,200	3.4	1,670	5.3	510	2.35	220	4.0	21,320
2.8	820	2.6	2,550	3.6	1,990	5.4	570	2.40	236	4.5	24,850
2.9	875	2.8	2,900	3.8	2,320	5.5	640	2.45	256	5.0	28,500
3.0	930	3.0	3,250	4.0	2,650	5.6	720	2.50	277	5.5	32,150
3.1	1,030	3.2	3,600	4.2	3,020	5.7	820	2.55	302	6.0	35,800
3.2	1,130	3.4	4,050	4.4	3,390	5.8	920	2.60	327	6.5	39,450
3.3	1,230	3.6	4,800	4.6	3,770	5.9	1,020	2.65	353	7.0	43,100
3.4	1,330	3.8	5,550	4.8	4,160	6.0	1,120	2.70	400	7.5	46,750
3.5	1,430	4.0	6,350	5.0	4,550	6.2	1,320	2.75	445	8.0	50,400
3.6	1,530	4.2	7,150	5.5	5,600	6.4	1,520	2.80	490	9.0	57,700
3.7	1,630	4.4	8,000	6.0	6,750	6.6	1,720	2.85	535	10.0	65,000
3.8	1,730	4.6	8,850	6.5	7,975	6.8	1,920	2.90	580	11.0	72,300
3.9	1,830	4.8	9,700	7.0	9,300	7.0	2,120	2.95	624	12.0	79,600
4.0	1,930	5.0	10,550	7.5	10,720	7.2	2,320	3.00	670	13.0	86,900
		5.2	11,400	8.0	12,275	7.4	2,520	3.05	715	14.0	94,200
		5.4	12,250	8.5	14,085	7.6	2,720	3.10	760	15.0	101,500
		5.6	13,100	9.0	16,100	7.8	2,920	3.15	797	16.0	108,800
		5.8	13,950	9.5	18,275	8.0	3,020	3.20	850	17.0	116,100
		6.0	14,800	10.0	20,600	8.5	3,570	3.25	895	18.0	123,400
		6.5	16,925	10.5	23,100	9.0	4,120	3.30	940	19.0	130,700
		7.0	19,050	11.0	25,600	9.5	4,670	3.35	985	20.0	138,000
		7.5	21,300	11.5	28,100	10.0	5,220	3.40	1,030	22.0	152,600
		8.0	23,550	12.0	30,600			3.45	1,075	24.0	167,200

GREAT LAKES DRAINAGE.

DESCRIPTION OF RIVER STATIONS.

Waterville station on Maumee River.—This station, established on November 19, 1898, by H. A. Pressey and B. H. Flynn, is located at the highway bridge, near Waterville, Ohio. The gagings are made from the upstream side of bridge, the zero being on the left bank and marked by a nail in the guard rail. The wire gage is referred to a bench mark cut in upstream side of abutment on left side of river, the elevation of which is 25.2 feet above the datum of the gage. The bed is rocky, the current strong, and is unaffected by the backwater from the lake. The observer is J. E. Harpel, Waterville, Ohio.

Mexico station on Sandusky River.—This station, established on November 17, 1898, by H. A. Pressey and B. H. Flynn, is at the highway bridge, near Mexico, about 40 miles above Fremont, Ohio, by river. The wire gage is on the upstream side of the bridge. It is referred to a bench mark, a cross cut in the top of upstream wing of right abutment of bridge. The elevation of bench mark is 30 feet above the datum of the gage. The gagings are made from the downstream side of bridge, the zero being on the right bank, marked by a nail in the guard rail. The bed of the river is rocky and the section unobstructed by piers. The observer is M. L. Estep.

Fremont station on Sandusky River.—This station, established on November 18, 1898, by H. A. Pressey and B. H. Flynn, is at the bridge of the Lake Shore Railway at Fremont. The gagings are made from board walk on lower cord of bridge, zero being a cross cut on bottom lateral at west end of bridge. The gage, an iron pipe graduated to feet and tenths, is located at the waterworks intake and referred to a bench mark cut on top of south end of west abutment of bridge. The elevation of bench mark is 20.1 feet above the datum of the gage. The bed is rocky and the banks high and not subject to overflow. The observer is Charles F. Reiff.

TABLES OF DAILY GAGE HEIGHT.

Daily gage height, in feet, of Maumee River at Waterville, Ohio, for 1898.

Day.	Nov.	Dec.	Day.	Nov.	Dec.	Day.	Nov.	Dec.	Day.	Nov.	Dec.
1	.....	2.55	9	.....	3.10	17	.....	3.80	25	2.90	8.45
2	.....	2.50	10	.....	2.50	18	.....	3.60	26	3.05	6.90
3	.....	2.60	11	.....	3.85	19	.....	2.90	27	2.55	6.70
4	.....	2.60	12	.....	3.40	20	3.80	3.60	28	2.70	6.00
5	.....	2.70	13	.....	3.25	21	3.60	5.60	29	2.65	5.10
6	.....	2.50	14	.....	3.85	22	3.55	7.80	30	2.60	4.70
7	.....	2.45	15	.....	3.95	23	3.15	9.40	31	.....	4.35
8	.....	2.40	16	.....	4.15	24	3.05	8.45			

Daily gage height, in feet, of Sandusky River at Mexico, Ohio, for 1898.

Day.	Nov.	Dec.	Day.	Nov.	Dec.	Day.	Nov.	Dec.	Day.	Nov.	Dec.
1	.....	1.50	9	.....	1.80	17	.....	1.50	25	1.60	5.10
2	.....	1.50	10	.....	1.80	18	2.20	1.50	26	1.60	4.50
3	.....	1.50	11	.....	1.80	19	2.10	1.60	27	1.60	3.40
4	.....	1.50	12	.....	1.80	20	2.00	6.30	28	1.50	3.10
5	.....	1.50	13	.....	1.80	21	1.90	11.90	29	1.50	3.00
6	.....	1.60	14	.....	1.70	22	1.80	13.00	30	1.50	2.90
7	.....	1.80	15	.....	1.70	23	1.80	9.90	31	.....	3.10
8	.....	1.80	16	.....	1.60	24	1.70	6.30			

Daily gage height, in feet, of Sandusky River at Fremont, Ohio, for 1898.

Day.	Nov.	Dec.	Day.	Nov.	Dec.	Day.	Nov.	Dec.	Day.	Nov.	Dec.
1	.....	1.10	9	.....	1.20	17	.....	1.00	25	1.25	2.65
2	.....	1.05	10	.....	1.00	18	2.00	.90	26	1.20	2.20
3	.....	1.00	11	.....	1.25	19	1.85	1.05	27	1.15	1.85
4	.....	1.10	12	.....	1.15	20	1.70	3.75	28	1.05	2.05
5	.....	1.35	13	.....	1.00	21	1.65	5.60	29	1.15	1.90
6	.....	1.60	14	.....	1.05	22	1.55	5.25	30	1.10	2.00
7	.....	1.50	15	.....	1.00	23	1.40	4.80	31	.....	2.10
8	.....	1.15	16	.....	1.00	24	1.30	3.50			

List of discharge measurements, 1898.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
				Feet.	*Sec.-feet.*
Nov. 19	Maumee River	Waterville, Ohio	H. A. Pressey	4.00	5,628
Nov. 17	Sandusky River	Mexico, Ohio	do	2.30	386
Nov. 18	do	Fremont, Ohio	do	2.00	645

UPPER MISSOURI RIVER DRAINAGE.

DESCRIPTION OF RIVER STATIONS.

Salesville station on West Gallatin River.—Described on page 66 of Paper No. 15; results for 1897 shown on pages 275–277 of the Nineteenth Annual Report, Part IV.

Bozeman station on Middle Creek.—Described on page 67 of Paper No. 15, and on page 271 of the Nineteenth Annual Report, Part IV. A wire cable was placed across the stream in 1898, 250 yards north of the gage station, and current meter measurements are made from this.

Logan station on Gallatin River.—Described on page 68 of Paper No. 15; results for 1897 shown on pages 277–278 of the Nineteenth Annual Report.

Redbluff station on Madison River.—Described on page 69 of Paper No. 15; results for 1897 shown on pages 279–280 of the Nineteenth Annual Report, Part IV.

Sappington station on Jefferson River.—Described on page 70 of Paper No. 15; results for 1897 shown on pages 281–283 of the Nineteenth Annual Report, Part IV. The observer since March 26, 1898, has been W. D. McClellan.

Townsend station on Missouri River.—Described on page 65 of Paper No. 15; results for 1897 shown on pages 283–285 of the Nineteenth Annual Report, Part IV.

Havre station on Milk River.—This station is at a point on Milk River about one-quarter mile northwest of Havre, Montana. Owing to the river changing its channel so often and banks dropping in, a special form of gage rod was erected by Mr. Cyrus C. Babb. This consists of a 4-inch by 4-inch timber placed horizontally on supports and extending out over the river 20 feet. This is graduated in feet and tenths, and over it is run a wire with a weight attached, which is lowered to the surface of the water when measurements are made. The wire gage has a length of 24.8 feet. The measurements for discharge are made by means of a cable of 200 feet span, swung across the river, on which a box is run by pulleys. This is so located that an excellent result can be obtained. No readings were had in 1898 when the water was above the normal height, as the "June rise" had subsided before the station was established, May 15, 1898. The observer is Henry O'Herren, rancher. The discharge measurements were made by C. W. Ling and others.

The old station at Chinook, described on page 73 of Paper No. 15, was maintained through 1897, but was found to be of doubtful value on account of the poor section and from the fact that a number of canals diverted water at points above. It was decided to move the station to Havre, the wire gage erected being similar to the one in use at Whitman station, on Wallawalla River, Washington. The horizontal timber or boom noted above extends over the bank, being made fast to two posts set firmly in the ground about 6 feet apart.

Livingston station on Yellowstone River.—Described on page 74 of Paper No. 15; results for 1897 shown on pages 287–289 of the Nineteenth Annual Report, Part IV.

Lovell station on Shoshone River.—Described on page 76 of Paper No. 15; results for 1897 shown on pages 290–293 of the Nineteenth Annual Report, Part IV.

Buffalo station on Clear Creek.—Described on page 78 of Paper No. 15; results for 1897 given on pages 297–298 of the Nineteenth Annual Report, Part IV.

Fort Niobrara station on Niobrara River.—Described on page 80 of Paper No. 15; results for 1897 shown on page 299 of the Nineteenth Annual Report, Part IV. No gage heights were observed during 1898.

TABLES OF DAILY GAGE HEIGHT.

Daily gage height, in feet, of West Gallatin River at Salesville, Montana, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	.....	.....	.....	2.80	3.85	5.20	4.80	3.70	3.40	3.20	3.20	3.00
2	2.90	4.10	.....	2.80	3.70	5.30	4.80	3.70	3.40	3.20	3.20	3.00
3	.....	.....	2.90	2.80	3.55	5.30	4.80	3.65	3.40	3.20	3.10	3.00
4	.....	.....	2.90	2.80	3.50	5.30	4.80	3.60	3.35	3.20	3.10	3.00
5	3.00	.....	2.90	2.80	3.50	5.30	4.80	3.60	3.30	3.20	3.10	3.00
6	.....	3.60	2.90	2.80	3.50	5.25	4.80	3.60	3.30	3.20	3.10	3.00
7	.....	.....	2.90	2.90	3.70	5.10	4.80	3.50	3.30	3.20	3.10	2.00
8	.....	.....	2.90	2.90	3.80	5.15	4.80	3.50	3.30	3.20	3.10	3.00
9	.....	.....	2.90	3.00	3.90	5.30	4.70	3.50	3.30	3.20	3.00	2.95
10	2.90	.....	2.90	3.00	3.90	5.45	4.60	3.50	3.30	3.20	3.00	2.90
11	.....	3.10	2.90	3.10	4.20	5.95	4.50	3.50	3.30	3.20	3.05	2.90
12	.....	.....	2.90	3.10	4.40	6.45	4.60	3.50	3.25	3.20	3.10	2.90
13	.....	.....	2.80	3.20	4.50	6.80	4.85	3.50	3.20	3.20	3.10	2.90
14	2.90	.....	2.80	3.30	4.80	7.20	4.65	3.50	3.20	3.20	3.10	2.90
15	.....	.....	2.80	3.40	4.80	6.95	4.55	3.45	3.20	3.20	3.10	3.00
16	.....	3.00	2.80	3.40	5.00	7.45	4.45	3.40	3.20	3.20	3.10	3.15
17	.....	.....	2.80	3.40	5.00	7.45	4.40	3.40	3.20	3.20	3.10	3.30
18	.....	.....	2.80	3.40	5.00	7.15	4.30	3.40	3.20	3.20	3.10	3.40
19	3.00	.....	2.80	3.20	4.80	7.05	4.20	3.40	3.20	3.20	3.05	3.40
20	.....	2.90	2.70	3.20	4.80	6.85	4.10	3.40	3.20	3.20	3.00	3.50
21	.....	.....	2.70	3.30	4.80	6.60	4.10	3.30	3.20	3.20	3.00	3.50
22	.....	.....	2.70	3.20	4.80	6.30	4.10	3.30	3.20	3.20	3.00	3.50
23	3.10	2.90	2.70	3.15	5.30	6.20	4.10	3.30	3.20	3.20	3.10	3.50
24	.....	.....	2.70	3.20	5.40	6.55	4.00	3.30	3.20	3.20	3.10	3.50
25	.....	.....	2.80	3.50	5.60	6.20	3.95	3.30	3.20	3.20	3.00	3.40
26	.....	.....	2.80	3.90	5.80	5.55	3.90	3.30	3.20	3.20	3.00	3.40
27	.....	.....	2.80	4.05	5.80	5.05	3.90	3.30	3.20	3.20	3.00	3.35
28	3.10	2.90	2.70	4.05	5.90	4.95	3.80	3.30	3.20	3.20	3.00	3.15
29	.....	.....	2.70	4.00	6.20	4.80	3.80	3.40	3.20	3.20	3.00	3.00
30	.....	.....	2.70	3.90	5.85	4.80	3.80	3.40	3.20	3.30	3.00	3.00
31	.....	.....	2.70	.....	5.80	.....	3.75	3.40	.....	3.30	.....	3.00

Daily gage height, in feet, of Middle Creek at Bozeman, Montana, for 1898.

Day.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	.....	0.40	0.80	0.60	0.15	0.05	0.00	.....	.....
2	.....	.35	.90	.55	.15	.05	— .01	.....	.....
3	.....	.45	.80	.50	.15	.05	.00	.....	.....
4	.....	.35	.90	.50	.15	.03	.00	.....	.....
5	.....	.30	1.10	.70	.15	.03	.00	0.00	.....
6	.....	.35	.80	.60	.10	.03	.00	.....	.....
7	.....	.40	.75	.65	.10	.05	.00	.....	.....
8	.....	.40	.75	.57	.10	.05	.00	.....	.....
9	.....	.43	.80	.60	.10	.03	.03	.....	.....
10	.....	.50	.40	.60	.10	.03	.03	.....	.....
11	.....	.60	.80	.60	.10	.03	.03	.....	.....
12	.....	.65	.95	.75	.10	.03	.03	.90	1.10
13	.....	.70	.80	.65	.08	.03	.03	.....	.....
14	.....	.70	2.10	.50	.08	.03	.00	.....	.....
15	.....	.70	2.00	.50	.10	.03	— .01	.....	.....
16	.....	.80	1.90	.50	.10	.03	— .01	.....	.....
17	.....	1.00	1.30	.45	.10	.03	.00	.....	.....
18	0.30	1.10	1.20	.40	.10	.03	.03	.....	.....
19	.30	.90	1.20	.35	.10	.00	.05	.....	— .05
20	.30	.80	1.10	.30	.10	— .01	.03	.....	.....
21	.35	.80	1.00	.30	.08	— .01	.00	— .90	.....
22	.40	.80	1.00	.30	.05	.00	.03	.....	.....
23	.42	.90	1.00	.30	.05	.00	.....	.....	.....
24	.46	.90	1.10	.30	.05	.00	.....	.....	.....
25	.65	.80	1.00	.30	.03	— .03	.....	.....	.....
26	.95	.75	.90	.25	.03	— .01	.....	.....	.....
27	.80	.90	1.00	.20	.03	.00	.....	.....	— .03
28	.60	.83	.90	.20	.03	.00	.....	.....	.....
29	.50	.75	.70	.20	.03	.00	.....	1.00	.....
30	.46	.80	.65	.20	.03	.00	.....	.....	.....
31	.....	.80	.....	.18	.05	.....	.....	.....	.....

Daily gage height, in feet, of Gallatin River at Logan, Montana, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	1.30	.....	1.10	1.00	1.85	3.80	2.55	0.70	0.70	1.20	1.20	(a)
2	.....	.....	1.10	1.00	1.80	4.10	2.40	.70	.70	1.15	1.20	(a)
3	.....	.....	1.10	1.00	1.70	3.80	2.15	.70	.70	1.10	1.20	(a)
4	.....	.....	1.10	1.00	1.55	3.70	2.00	.70	.70	1.10	1.20	(a)
5	.....	.....	1.10	1.10	1.50	3.60	1.85	.70	.70	1.10	1.20	(a)
6	.....	.....	1.10	1.00	1.40	3.50	1.75	.70	.70	1.10	1.20	(a)
7	.....	(b)	1.10	1.00	1.40	3.50	1.65	.70	.80	1.10	1.20	(a)
8	1.00	.....	1.00	1.00	1.40	3.50	1.60	.70	.80	1.10	1.15	(a)
9	.....	.....	1.00	1.10	1.40	3.55	1.55	.70	.80	1.10	1.10	(a)
10	.....	.....	.95	1.35	1.50	3.70	1.50	.70	.90	1.10	1.10	(a)
11	.....	.....	1.00	1.55	1.55	3.95	1.50	.70	.90	1.10	1.10	(a)
12	.....	1.00	1.00	1.45	1.80	4.30	1.50	.70	1.00	1.10	1.10	(a)
13	.....	.....	1.00	1.40	2.15	4.55	1.50	.70	1.00	1.20	1.10	(a)
14	.....	.....	1.00	1.50	2.25	4.75	1.60	.70	1.00	1.20	1.10	(a)
15	1.60	.....	1.00	1.55	2.30	5.05	1.50	.70	1.00	1.20	1.10	(a)
16	.....	.....	1.00	1.60	2.50	5.20	1.40	.70	1.00	1.20	1.10	(a)
17	.....	1.00	.90	1.50	2.80	5.15	1.35	.70	1.00	1.20	1.10	(a)
18	.....	.....	.90	1.40	3.00	5.20	1.15	.70	1.00	1.20	1,10	(a)
19	.....	1.10	1.00	1.40	3.08	5.25	1.10	.70	1.00	1.20	1.10	(a)
20	.....	.....	1.00	1.40	3.00	5.25	1.00	.70	1.00	1.20	1.10	(a)
21	.....	.....	1.00	1.40	2.90	5.00	1.00	.70	1.00	1.20	1.10	(a)
22	1.60	.....	1.00	1.40	2.70	4.30	.90	.70	1.00	1.20	(a)	(a)
23	.....	.....	1.00	1.40	2.85	4.10	.90	.70	1.00	1.20	(a)	(a)
24	.....	.....	1.00	1.40	3.00	4.30	.90	.70	1.00	1.20	(a)	(a)
25	.....	.....	1.00	1.50	3.00	4.15	.80	.70	1.00	1.20	(a)	(a)
26	.....	1.00	1.00	1.70	3.15	3.90	.80	.70	1.00	1.20	(a)	(a)
27	.....	.....	1.00	1.95	3.50	3.55	.80	.70	1.10	1.20	(a)	(a)
28	.....	.....	1.00	2.00	3.60	3.30	.70	.70	1.10	1.20	(a)	(a)
29	(a)	.....	1.00	1.90	3.90	2.85	.70	.70	1.10	1.20	(a)	(a)
30	.....	.....	1.00	1.90	4.25	2.65	.70	.70	1.10	1.20	(a)	(a)
31	.....	.....	1.00	.....	3.90	.....	.70	.....	.....	1.20	.....	(a)

a Frozen at gage. *b* Ice flowed out February 7.

Daily gage height, in feet, of Madison River at Redbluff, Montana, for 1898.

Day.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	.....	2.50	1.90	1.60	1.60	1.40	1.40	(a)
2	.....	2.60	1.90	1.60	1.60	1.40	1.40	(a)
3	.....	2.80	2.00	1.60	1.60	1.40	1.40	(a)
4	.....	2.50	2.00	1.60	1.60	1.40	1.40	(a)
5	.....	2.30	2.00	1.60	1.55	1.40	1.40	(a)
6	.....	2.30	2.00	1.60	1.45	1.40	1.40	(a)
7	1.65	2.20	2.00	1.60	1.40	1.40	1.40	(a)
8	1.70	2.20	1.90	1.60	1.40	1.40	1.40	(a)
9	1.70	2.20	1.95	1.60	1.40	1.40	1.40	(a)
10	1.70	2.35	2.00	1.60	1.40	1.40	1.40	(a)
11	1.70	2.40	2.00	1.60	1.40	1.40	1.40	(a)
12	1.90	2.50	2.00	1.60	1.40	1.40	1.40	(a)
13	2.00	2.55	2.10	1.60	1.40	1.40	1.40	(a)
14	2.00	2.95	2.00	1.60	1.40	1.40	1.40	(a)
15	2.10	2.95	2.00	1.60	1.40	1.40	(a)	(a)
16	2.30	3.05	2.00	1.60	1.40	1.40	(a)	(a)
17	2.50	3.15	2.00	1.70	1.40	1.40	(a)	(a)
18	2.55	3.20	1.85	1.70	1.40	1.40	(a)	(a)
19	2.60	3.20	1.80	1.70	1.40	1.40	(a)	(a)
20	2.55	3.10	1.80	1.50	1.40	1.40	(a)	(a)
21	2.35	3.00	1.80	1.50	1.40	1.40	(a)	(a)
22	2.10	2.95	1.70	1.50	1.40	1.40	(a)	(a)
23	2.10	2.65	1.75	1.50	1.40	1.40	(a)	(a)
24	2.40	2.60	1.70	1.40	1.40	1.40	(a)	(a)
25	2.30	2.50	1.70	1.40	1.40	1.40	(a)	(a)
26	2.30	2.55	1.60	1.40	1.40	1.40	(a)	(a)
27	2.50	2.30	1.60	1.40	1.40	1.40	(a)	(a)
28	2.70	2.20	1.60	1.60	1.40	1.45	(a)	(a)
29	2.70	2.00	1.60	1.55	1.40	1.45	(a)	(a)
30	2.70	1.80	1.60	1.50	1.40	1.40	(a)	(a)
31	2.55	.....	1.60	1.50	.....	1.40	(a)	(a)

a Frozen at gage.

Daily gage height, in feet, of Jefferson River at Sappington, Montana, for 1898.

Day.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	a 2.00	1.60	3.50	5.75	3.60	1.50	1.00	1.30	1.70	(b)
2	1.70	1.60	3.35	5.60	3.75	1.40	1.00	1.30	1.70	(b)
3	1.60	1.60	3.20	5.55	4.05	1.40	1.00	1.30	1.70	(b)
4	1.60	1.65	3.05	5.35	4.05	1.30	1.75	1.30	1.70	(b)
5	1.60	1.65	2.95	5.25	3.70	1.30	1.55	1.30	1.70	(b)
6	1.60	1.70	2.85	5.05	3.40	1.30	1.50	1.30	1.70	(b)
7	1.60	1.80	2.70	4.85	3.15	1.30	1.50	1.40	1.70	(b)
8	1.65	1.80	2.70	4.65	2.95	1.20	1.50	1.40	1.70	(b)
9	1.70	1.80	2.70	4.60	2.75	1.20	1.50	1.40	1.60	(b)
10	1.60	1.80	2.70	4.55	2.70	1.20	1.50	1.45	1.60	(b)
11	1.60	2.00	2.80	4.65	2.70	1.20	1.40	1.50	1.60	(b)
12	1.60	2.10	2.85	4.75	2.75	1.10	1.40	1.50	1.60	(b)
13	1.60	2.10	3.10	4.90	2.85	1.10	1.40	1.50	1.60	(b)
14	1.60	2.15	3.30	5.40	2.95	1.10	1.40	1.50	1.60	(b)
15	1.55	2.45	3.50	5.60	2.85	1.10	1.30	1.50	1.60	(b)
16	1.50	2.75	3.75	5.75	2.80	1.10	1.30	1.55	1.60	(b)
17	1.50	3.20	4.10	5.80	2.80	1.10	1.30	1.60	1.70	(b)
18	1.50	3.65	4.25	5.80	2.80	1.00	1.30	1.60	1.70	(b)
19	1.50	4.30	4.50	5.80	2.70	1.00	1.30	1.60	1.70	(b)
20	1.50	3.85	4.65	5.75	2.55	1.00	1.30	1.60	1.70	(b)
21	1.50	3.50	4.65	5.65	2.35	1.00	1.25	1.60	1.70	(b)
22	1.50	3.50	4.60	5.50	2.25	1.00	1.20	1.60	1.70	(b)
23	1.40	3.40	4.55	5.05	2.15	1.00	1.20	1.65	1.70	(b)
24	1.35	3.30	4.85	4.85	2.00	1.00	1.20	1.70	1.70	(b)
25	1.30	3.30	4.95	4.55	1.90	1.00	1.20	1.70	1.70	(b)
26	1.30	3.40	4.75	4.35	1.80	1.00	1.20	1.70	1.70	(b)
27	1.30	3.50	4.65	4.10	1.70	1.00	1.30	1.70	1.70	(b)
28	1.45	3.55	4.95	3.80	1.70	1.00	1.30	1.70	1.70	(b)
29	1.55	3.70	5.65	3.55	1.70	1.00	1.30	1.70	1.70	(b)
30	1.65	3.65	6.05	3.50	1.60	1.00	1.30	1.70	1.85	(b)
31	1.60	.....	5.90	.....	1.60	1.00	.....	1.70	.....	(b)

a River frozen from January 1 to February 28. b Frozen at gage.

Daily gage height, in feet, of Missouri River, at Townsend, Montana, for 1898. (a)

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.
1	92.04	91.79	89.49	88.84	90.34	93.04	90.84	88.74	88.54	88.64	88.99
2	92.01	91.84	89.34	88.91	90.21	92.79	90.84	88.74	88.54	88.64	89.04
3	91.94	91.89	89.14	88.96	90 04	92.59	90.89	88.69	88.54	88.64	89.04
4	91.84	91.99	89.89	89.01	89.81	92.49	90.91	88.64	88.54	88.64	89.04
5	91.87	92.04	88.84	89.04	89.69	92.41	90.74	88.64	88.59	88.64	89.04
6	91.64	92.04	88.84	89.04	89.64	92.31	90.49	88.64	88.64	88.64	88.99
7	91.46	92.04	88.84	89.04	89.64	92.19	90.31	88.64	88.74	88.64	88.94
8	91.44	92.04	88.79	89.04	89.69	91.99	90.11	88.64	88.74	88.64	88.94
9	91.44	92.04	88.74	89.04	89.84	91.91	90.01	88.64	88.74	88.64	88.91
10	91.44	92.04	88.74	89.04	89.89	92.01	89.94	88.64	88.74	88.64	88.84
11	91.44	92.04	88.74	89.26	90.04	92.04	89.89	88.64	88.74	88.69	88.84
12	91.44	92.04	88.74	89.39	90.14	92.09	89.84	88.59	88.74	88.74	88.84
13	91.44	92.04	88.74	89.56	90.34	92.29	89.84	88.54	88.74	88.76	88.84
14	91.44	92.04	88.74	89.61	90.59	92.64	89.84	88.54	88.74	88.84	88.84
15	91.51	92.04	88.74	89.64	90.69	92.96	89.84	88.54	88.74	88.84	88.79
16	91.54	92.04	88.74	89.71	90.64	93.29	89.84	88.54	88.74	88.84	88.74
17	91.54	91.99	88.74	90.06	90.54	93.49	89.84	88.54	88.69	88.84	88.74
18	91.54	91.94	88.74	90.24	90.46	93.64	89.71	88.54	88.69	88.84	88.74
19	91.54	91.94	88.74	90.49	90.44	93.54	89.51	88.54	88.66	88.89	b88.74
20	91.56	91.94	88.74	90.46	90.41	93.46	89.44	88.54	88.64	88.91	.....
21	91.61	92.01	88.74	90.26	90.34	93.29	89.39	88.54	88.64	88.94	.....
22	91.71	92.04	88.74	90.21	90.59	93.09	89.34	88 54	88.64	88.96	.....
23	91.74	92.04	88.74	90.19	90.89	92.89	89.26	88.54	88.64	88.99	.....
24	91.74	92.04	88.74	90.16	91.24	92.49	89.16	88.54	88.64	88.99	.....
25	91.74	92.04	88.86	90.14	91.54	92.09	89.09	88.54	88.64	89.04	.....
26	91.74	89.79	92.04	90.21	91.74	91.91	89.04	88.54	88.64	89.04	.....
27	91.74	89.59	92.04	90.24	92.29	91.81	88.96	88.49	88.64	89.04	.....
28	91.74	89.54	92.04	90.24	92.59	91.34	88.89	88.49	88.64	89.04	.....
29	91.74	.....	88.74	90.31	92.79	90.74	88.81	88.54	88.64	89.04	.....
30	91.74	.....	88.74	90.34	92.86	90.79	88.74	88.54	88.64	89.04	.....
31	91.74	.....	88.79	.....	92.99	.....	88.74	88.54	.....	89.04	.....

a Readings taken to surface of ice from January 1 to February 25, and from March 22 to 28.
b Discontinued.

Daily gage height, in feet, of Milk River at Havre, Montana, for 1898.

Day.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	.....	3.75	1.90	1.30	1.00	0.50	1.30	.....
2	.....	3.70	1.90	1.30	1.00	.50	1.30	.....
3	.....	3.90	1.85	1.25	1.20	.85	1.30	.....
4	.....	3.75	1.70	1.20	1.30	1.05	1.30	.....
5	.....	3.60	1.70	1.20	1.20	1.10	1.30	1.50
6	.....	3.40	1.65	1.30	1.35	1.20	1.30	1.50
7	.....	3.30	1.70	1.30	1.20	1.20	1.30	1.50
8	.....	3.10	1.50	1.20	1.10	1.20	1.30	1.50
9	.....	3.00	1.50	1.10	1.00	1.20	1.40	1.50
10	.....	2.90	.50	1.10	.90	1.25	1.30	1.50
11	.....	2.90	.40	1.10	1.00	1.30	1.30	1.40
12	.....	2.75	.40	1.10	1.00	1.40	1.30	1.40
13	.....	2.65	.30	1.00	.80	1.50	1.40	1.40
14	.....	2.70	.80	1.00	.80	1.40	1.30	1.40
15	2.90	2.75	1.30	.90	.85	1.30	1.25	1.40
16	2.90	3.10	(a)	.90	.85	1.30	1.25	1.40
17	3.40	2.75	(a)	.80	.80	1.20	1.30	1.40
18	3.25	2.65	(a)	.80	.80	1.10	1.35	1.40
19	3.10	2.60	1.35	.80	.80	1.10	1.30	1.40
20	3.80	2.75	1.55	.80	.75	1.10	.....	1.40
21	3.20	2.85	1.70	.80	.70	1.00	.....	1.40
22	3.00	2.60	1.60	.70	.70	1.15	.....	1.40
23	3.00	2.50	1.60	.70	.70	1.30	.....	1.40
24	2.85	2.45	2.50	2.45	.65	1.25	.....	1.40
25	2.70	2.45	1.90	2.05	.70	1.40	.....	.....
26	2.40	2.40	1.90	1.75	.70	1.40	.....	1.40
27	2.55	2.30	1.80	1.60	.70	1.50	.....	1.40
28	2.50	2.20	1.65	1.30	.70	1.40	.....	.....
29	2.60	2.05	1.45	1.15	.60	1.40	.....	.....
30	2.50	1.80	1.35	1.00	.50	1.40	.....	.....
31	2.50	.....	1.30	1.00	.....	1.30	.....	1.40

a July 16, 17, 18 river changed channel, leaving gage without water.

Daily gage height, in feet, of Yellowstone River at Livingston, Montana, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	.....	.....	1.15	1.10	2.65	5.05	5.25	3.13	2.38	1.60	1.20	0.95
2	.....	.....	1.10	1.10	2.45	4.88	5.25	3.08	2.25	1.60	1.20	.....
3	.....	.....	1.08	1.10	2.33	4.75	5.13	3.03	2.28	1.48	1.20	.....
4	.....	0.90	1.05	1.10	2.20	4.50	5.03	2.98	2.33	1.48	1.20	.....
5	.....	.....	1.05	1.08	2.15	4.60	4.98	2.90	2.25	1.45	1.20	.....
6	.....	.....	1.10	1.05	2.08	4.38	4.98	2.90	2.13	1.45	1.20	.....
7	0.90	.....	1.10	1.05	2.15	4.38	4.88	2.85	2.05	1.40	1.20	.....
8	.....	.....	1.10	1.10	2.43	4.53	4.83	2.78	2.00	1.40	1.20	.....
9	.....	.....	1.10	1.08	2.63	4.83	4.83	2.75	2.00	1.40	.90	.....
10	.....	.....	1.00	1.15	2.70	5.05	4.65	2.70	1.90	1.45	.90	.....
11	.....	.85	1.00	1.25	3.38	5.33	4.60	2.65	1.85	1.50	1.15	.....
12	.....	.....	1.00	1.25	3.83	5.45	4.63	2.60	1.85	1.55	1.10	.....
13	.....	.....	.95	1.25	3.88	5.68	4.83	2.55	1.85	1.50	1.05	.....
14	.65	.....	.95	1.40	3.93	6.30	4.63	2.55	1.80	1.48	1.05	.....
15	.....	.....	.90	1.55	4.18	6.70	4.58	2.55	1.80	1.45	1.05	.....
16	.....	.....	.90	1.80	4.25	6.85	4.50	2.58	1.80	1.40	1.10	.....
17	.....	.....	.82	1.83	4.40	7.15	4.35	2.60	1.80	1.40	1.13	.....
18	.....	.90	.85	1.85	4.30	7.55	4.20	2.58	1.75	1.40	1.10	.80
19	.....	.....	.90	1.78	4.25	7.55	4.10	2.48	1.75	1.35	1 10	.....
20	.....	.....	.90	1.70	4.10	7.38	3.85	2.43	1.70	1.30	(a)	.....
21	.85	.....	.80	1.75	3.90	6.65	3.85	2.35	1.68	1.30	(a)	.....
22	.....	.....	(a)	1.83	3.75	6.25	3.75	2.30	1.65	1.30	(a)	.80
23	.....	.....	(a)	1.95	4.05	6.35	3.70	2.30	1.60	1.30	.95	.....
24	.....	.....	(a)	1.88	4.78	6.50	3.65	2.28	1.60	1.30	.90	.....
25	.....	1.15	(a)	1.95	4.78	6.40	3.60	2.20	1.60	1.25	.90	.....
26	.....	.....	(a)	2.48	4.98	5.85	3.53	2.15	1.55	1.25	(a)	.....
27	.....	.....	(a)	3.15	5.33	5.55	3.48	2.15	1.53	1.20	(a)	.....
28	.90	.....	(a)	3.03	5.90	5.53	3.38	2.60	1.50	1.20	.95	.....
29	.....	.....	(a)	2.85	5.68	5.38	3.33	2.30	1.50	1.20	.98	.80
30	.....	.....	1.10	2.83	5.38	5.25	3.23	2.30	1.50	1.20	.95	.....
31	.....	.....	1.10	.....	5.30	.....	3.15	2.68	.....	1.20	.....	.....

a Ice gorge in river.

Daily gage height, in feet, of Shoshone River at Lovell, Wyoming, for 1898.

Day.	Apr.	May.	June.	July.	Aug.	Sept.	Day.	Apr.	May.	June.	July.	Aug.	Sept.
1	—0.80	0.00	1.30	1.60	0.10	+0.40	17	+0.20	1.70	3.00	1.60	—0.40	—0.90
2	— .80	.00	1.40	1.40	.20	— .80	18	+ .00	1.70	3.50	1.30	+ .10	—1.00
3	— .90	—.40	1.40	1.30	.30	+ .50	19	— .80	3.00	3.60	.80	— .90	—1.00
4	— .80	—.30	1.20	1.30	.50	— .10	20	— .80	2.70	3.50	.70	— .50	—1.10
5	— .80	—.40	1.40	1.70	.30	— .40	21	— .90	1.80	3.30	.70	— .60	—1.10
6	— .80	—.40	1.00	2.00	.30	— .40	22	— .30	1.80	3.00	.70	— .60	—1.10
7	— .60	—.40	.90	2.20	.10	— .80	23	— .80	1.70	3.40	.60	— .60	—1.20
8	— .70	—.30	.90	2.10	.20	— .80	24	— .30	2.80	3.20	.60	— .70	—1.20
9	— .70	—.30	1.30	2.10	.30	— .80	25	— .30	2.30	3.20	.60	— .80	—1.20
10	— .50	+.10	1.80	2.30	.40	— .80	26	+ .70	2.20	3.00	.40	— .90	—1.20
11	— .50	.80	1.90	2.40	.40	— .90	27	1.00	2.20	2.50	.40	— .90	—1.20
12	— .50	.70	2.20	2.20	.50	— .90	28	.70	4.00	2.50	.30	+ .10	—1.20
13	— .30	.50	2.10	2.60	.60	— .90	29	.20	2.20	2.00	.20	.70	—1.30
14	— .20	1.00	2.70	2.40	.50	— .90	30	.10	2.20	2.30	.10	.30	—1.30
15	+ .10	1.00	2.80	2.10	.40	— .90	31	.....	1.60	.....	.10	.40	.....
16	+ .30	.70	3.20	2.00	— .40	— .90							

Daily gage height, in feet, of Clear Creek at Buffalo, Wyoming, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	.....	.....	.....	.....	.....	2.45	1.35	0.80	0.30	.....	.....	.....
2	.....	.....	.....	.....	.....	2.48	1.30	.85	.30	.....	.....	.....
3	.....	.....	.....	.....	.....	2.10	1.30	.80	.30	.....	0.43	0.36
4	.....	.....	.....	.....	.....	2.10	1.30	.80	.35	.....	.....	.....
5	.....	.....	.....	.....	.....	1.70	.....	.80	.35	.....	.....	.....
6	0.37	.....	0.35	.....	.....	1.95	.....	.80	.35	0.60	.....	.....
7	.....	0.32	.....	.....	.....	1.70	.....	.80	.35	.60	.....	.....
8	.....	.....	.....	.....	.....	1.60	.....	.85	.35	.55	.....	.....
9	.....	.....	.....	.....	.....	2.00	.....	.80	.40	.55	.....	.....
10	.....	.....	.....	.....	.....	2.10	1.22	.70	.40	.55	.42	.....
11	.....	.....	.....	.....	.....	1.90	1.15	.65	.40	.55	.....	.35
12	.....	.34	.....	.....	.....	2.20	1.15	.70	.40	.55	.....	.....
13	.....	.....	.35	.....	.....	2.60	1.25	.70	.40	.55	.....	.....

Daily gage height, in feet, of Clear Creek at Buffalo, Wyoming, for 1898—Cont'd.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
14	.....	.....	.....	.....	.....	(a)	1.25	.50	.40	.55	.....	.....
15	.35	.....	.....	.....	0.95	2.45	1.30	.45	.40	.55	.....	.....
16	.....	.....	.....	.....	1.15	2.45	1.45	.45	.45	.55	.....	.....
17	.....	.....	.....	.....	1.47	2.60	1.25	.50	.45	.50	.40	.....
18	.....	.....	.....	.....	1.35	2.20	1.15	.50	.45	.55	.....	.32
19	.....	.....	.....	.....	1.30	2.10	1.10	.50	.45	.55	.....	.....
20	.....	.....	.37	.....	1.45	2.10	1.05	.50	.45	.55	.....	.....
21	.....	.34	.....	.....	1.30	2.10	1.00	.45	.50	.55	.....	.....
22	.35	.....	.....	.....	1.30	1.95	1.00	.40	.50	.55	.....	.....
23	.....	.....	.....	.....	1.30	1.95	1.00	.40	.50	.55	.....	.....
24	.....	.....	.....	.....	2.65	1.90	1.00	.40	.50	.50	.....	.....
25	.....	.....	.....	.....	2.70	1.75	.95	.40	.50	.50	.40	.....
26	.....	.....	.....	.....	2.60	1.70	.95	.40	.45	.50	.....	.32
27	.....	.35	.40	.....	.....	1.55	.90	.40	.45	.50	.....	.....
28	.....	.....	.....	.....	.....	1.50	.90	.40	.45	.....	.....	.....
29	.....	.....	.....	.....	3.00	1.45	.85	.40	.....	.....	.....	.....
30	.30	.....	.....	.....	(a)	1.45	.85	.35	.....	.....	.....	.....
31	.....	.....	.....	.....	2.09	.....	.80	.30	.....	.....	.....	.....

a High water.

List of discharge measurements, 1898.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
				Feet.	*Sec.-feet.*
Apr. 17	West Gallatin River.	Salesville, Mont	Roe Emery	3.40	942
June 9	do	do	do	5.40	3,636
June 18	do	do	C. C. Babb	7.20	6,759
July 18	do	do	Roe Emery	4.30	1,734
Aug. 12	do	do	do	3.50	965
Sept. 7	do	do	do	3.35	1,010
Sept. 23	do	do	do	3.25	981
Oct. 9	do	do	do	3.20	653
Oct. 26	do	do	do	3.30	632
Nov. 16	do	do	do	3.10	480
Apr. 16	Middle Creek	Bozeman, Mont	do	.30	65
May 22	do	do	do	.85	225
June 17	do	do	C. C. Babb	1.20	482
July 17	do	do	Roe Emery	.40	223
Aug. 2	do	do	do	.15	86
Aug. 4	do	do	do	.12	79
Aug. 14	do	do	do	.07	51
Sept. 6	do	do	do	.05	71
Sept. 21	do	do	do	.00	81
Oct. 9	do	do	do	.05	76
Oct. 25	do	do	do	.03	79
Nov. 5	do	do	do	.05	80
Apr. 21	Gallatin River	Logan, Mont	do	1.40	989
May 18	do	do	do	3.05	2,823
June 7	do	do	do	3.50	3,718
June 23	do	do	C. C. Babb	4.10	4,900
July 23	do	do	Roe Emery	.90	595
Aug. 6	do	do	do	.70	336
Aug. 17	do	do	do	.70	331
Sept. 11	do	do	do	.90	567
Sept. 24	do	do	do	1.00	1,025
Oct. 5	do	do	do	1.10	861
Oct. 29	do	do	do	1.20	779
Nov. 12	do	do	do	1.10	689
Apr. 30	Madison River	Redbluff, Mont	do	1.40	2,690
June 10	do	do	do	2.40	5,542
June 25	do	do	C. C. Babb	2.60	5,895
July 20	do	do	Roe Emery	1.60	2,849
Aug. 10	do	do	do	1.40	a 2,120
Sept. 9	do	do	do	1.40	1,956
Sept. 29	do	do	do	1.40	1,928
Oct. 10	do	do	do	1.40	2,299
Nov. 17	do	do	do	1.40	1,784
Apr. 21	Jefferson River	Sappington, Mont	do	3.52	5,007
June 24	do	do	C. C. Babb	4.70	7,700
July 23	do	do	Roe Emery	2.17	2,551
Aug. 8	do	do	do	1.20	1,079
Sept. 10	do	do	do	1.35	1,109
Sept. 16	do	do	do	1.30	1,184
Oct. 7	do	do	do	1.40	1,209

a Cherry Creek at Redbluff on August 10 discharged 5 second-feet.

List of discharge measurements, 1898—Continued.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
				Feet.	*Sec.-feet.*
Oct. 29	Jefferson River	Sappington, Mont.	Roe Emery	1.70	1,538
Nov. 11	do	do	do	1.60	1,386
Apr. 20	Missouri River	Townsend, Mont	do	90.52	7,775
May 26	do	do	do	91.80	15,976
July 2	do	do	C. C. Babb	90.90	8,954
July 26	do	do	Roe Emery	89.10	4,778
Aug. 5	do	do	do	88.70	2,494
Aug. 30	do	do	do	88.60	2,421
Sept. 17	do	do	do	88.75	2,721
Oct. 8	do	do	do	88.70	3,084
Oct. 22	do	do	do	89.00	3,749
Nov. 10	do	do	do	88.90	2,709
Apr. 26	Milk River	Havre, Mont	do	5.70	1,701
May 24	do	do	do	2.80	1,306
June 29	do	do	C. C. Babb	1.95	171
July 29	do	do	do	1.40	145
Aug. 4	do	do	C. W. Ling	.60	118
Aug. 13	do	do	do	.40	77
Aug. 24	do	do	do	2.00	457
Aug. 26	do	do	do	1.70	194
Sept. 5	do	do	do	1.20	106
Sept. 24	do	do	do	.60	44
Sept. 30	do	do	do	.80	31
Oct. 4	do	do	do	1.40	96
Oct. 6	do	do	do	1.50	105
Oct. 10	do	do	do	1.60	119
Oct. 12	do	do	do	1.70	132
Oct. 13	do	do	do	1.80	158
Oct. 14	do	do	do	1.70	125
Oct. 20	do	do	do	1.10	89
Oct. 24	do	do	do	1.30	120
Oct. 26	do	do	do	1.50	133
Nov. 1	do	do	do	1.40	115
Nov. 14	do	do	do	1.10	64
Nov. 15	do	do	do	1.20	84
Nov. 16	do	do	do	1.10	86
Nov. 17	do	do	do	1.10	92
Nov. 18	do	do	do	1.10	83

Rating tables.

Salesville.		Bozeman.		Logan.		Redbluff.		Sappington.	
Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Sec.-feet.*	*Feet.*	*Sec.-feet.*	*Feet.*	*Sec.-feet.*	*Feet.*	*Sec.-feet.*	*Feet.*	*Sec.-feet.*
4.3	1,745	—0.5	335	0.5	200	1.0	850	1.2	1,080
4.4	1,919	— .4	350	.6	280	1.1	1,175	1.3	1,150
4.5	2,093	— .3	365	.7	370	1.2	1,500	1.4	1,230
4.6	2,267	— .2	380	.8	460	1.3	1,825	1.5	1,310
4.7	2,441	— .1	395	.9	550	1.4	2,150	1.6	1,390
4.8	2,615	.0	410	1.0	640	1.5	2,475	1.7	1,540
4.9	2,789	.1	425	1.1	730	1.6	2,800	1.8	1,700
5.0	2,963	.2	440	1.2	820	1.7	3,125	1.9	1,900
5.1	3,137	.3	455	1.3	910	1.8	3,450	2.0	2,100
5.2	3,311	.4	470	1.4	1,000	1.9	3,775	2.1	2,300
5.3	3,485	.5	485	1.5	1,120	2.0	4,100	2.2	2,500
5.4	3,659	.6	500	1.6	1,240	2.1	4,425	2.3	2,700
5.5	3,833	.7	515	1.7	1,360	2.2	4,750	2.4	2,900
5.6	4,007	.8	530	1.8	1,480	2.3	5,075	2.5	3,100
5.7	4,181	.9	545	1.9	1,600	2.4	5,400	2.6	3,300
5.8	4,355	1.0	560	2.0	1,720	2.5	5,725	2.7	3,500
5.9	4,529	1.1	575	2.2	1,990	2.6	6,050	2.8	3,700
6.0	4,703	1.2	590	2.4	2,260	2.7	6,375	2.9	3,900
6.2	5,051	1.3	605	2.6	2,530	2.8	6,700	3.0	4,100
6.4	5,399	1.4	620	2.8	2,800	2.9	7,025	3.2	4,500
6.6	5,747	1.5	635	3.0	3,070	3.0	7,350	3.4	4,900
6.8	6,095	1.6	650	3.2	3,340	3.1	7,675	3.6	5,300
7.0	6,443	1.7	665	3.4	3,610	3.2	8,000	3.8	5,700
7.2	6,791	1.8	680	3.6	3,880	3.3	8,325	4.0	6,120
7.4	7,139	1.9	695	3.8	4,150	3.4	8,650	4.2	6,520
7.6	7,487	2.0	710	4.0	4,420	3.5	8,975	4.4	6,920
7.8	7,835	2.1	725	4.2	4,690	.....	.....	4.6	7,320
8.0	8,183	2.2	740	4.4	4,960	.....	.....	4.8	7,720
.....	.....	2.3	755	4.6	5,230	.....	.....	5.0	8,130
.....	.....	2.4	770	4.8	5,500	.....	.....	.....	.....

Rating tables—Continued.

Townsend.		Havre.		Livingston.		Lovell.		Buffalo.	
Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Sec.-feet.*	*Feet.*	*Sec.-feet.*	*Feet.*	*Sec.-feet.*	*Feet.*	*Sec.-feet.*	*Feet.*	*Sec.-feet.*
88.0	1,200	0.4	0	1.0	1,900	−0.8	310	0.1	4
88.2	1,500	.5	11	1.2	2,192	−.7	360	.2	9
88.4	1,900	.6	22	1.4	2,484	−.6	430	.3	17
88.6	2,360	.7	33	1.6	2,776	−.5	500	.4	25
88.8	3,090	.8	44	1.8	3,068	−.4	600	.5	33
89.0	3,670	.9	55	2.0	3,360	−.3	700	.6	46
89.2	4,310	1.0	66	2.2	3,652	−.2	800	.7	64
89.4	4,950	1.1	77	2.4	3,944	−.1	920	.8	82
89.6	5,620	1.2	88	2.6	4,236	−.0	1,080	.9	104
89.8	6,320	1.3	99	2.8	4,528	.1	1,250	1.0	134
90.0	7,020	1.4	110	3.0	4,820	.2	1,450	1.1	169
90.2	7,720	1.5	125	3.2	5,112	.3	1,650	1.2	209
90.4	8,420	1.6	140	3.4	5,404	.4	1,900	1.3	246
90.6	9,120	1.7	165	3.6	5,750	.5	2,190	1.4	286
90.8	9,820	1.8	200	3.8	6,200	.6	2,480	1.5	323
91.0	10,570	1.9	290	4.0	6,850	.7	2,770	1.6	365
91.2	11,410	2.0	380	4.2	7,773	.8	3,060	1.7	406
91.4	12,360	2.1	494	4.4	8,696	.9	3,350	1.8	447
91.6	13,380	2.2	608	4.6	9,620	1.0	3,640	1.9	504
91.8	14,460	2.3	722	4.8	10,543	1.2	4,220	2.0	558
92.0	15,660	2.4	836	5.0	11,467	1.4	4,800	2.1	607
92.2	16,770	2.5	950	5.2	12,390	1.6	5,380	2.2	657
92.4	17,900	2.6	1,064	5.4	13,313	1.8	5,960	2.3	705
92.6	19,090	2.7	1,178	5.6	14,237	2.0	6,540	2.4	752
92.8	20,160	2.8	1,292	5.8	15,160	2.2	7,120	2.5	808
93.0	21,290	2.9	1,406	6.0	16,084	2.4	7,700	.....	.....
93.2	22,420	3.0	1,520	6.2	17,008	2.6	8,280	.....	.....
93.4	23,560	.....	.....	6.4	17,931	2.8	8,860	.....	.....
93.6	24,720	.....	.....	6.6	18,854	3.0	9,440	.....	.....
93.8	25,880	.....	.....	6.8	19,778	.....	.....	.....	.....

PLATTE RIVER DRAINAGE.

DESCRIPTION OF RIVER STATIONS.

Woods Landing station on Laramie River.—Described on page 81 of Paper No. 15; results for 1897 given on pages 300–302 of the Nineteenth Annual Report, Part IV.

Uva station on Laramie River.—Described on page 82 of Paper No. 15; results for 1897 given on pages 302–304 of the Nineteenth Annual Report, Part IV.

Orin Junction station on North Platte River.—Described on page 83 of Paper No. 15; results for 1897 given on pages 304–307 of the Nineteenth Annual Report, Part IV.

Gering station on North Platte River.—Described on page 84 of Paper No. 15; results for 1897 given on pages 304–308 of the Nineteenth Annual Report, Part IV. This station was discontinued October 31, 1898.

Camp Clarke station on North Platte River.—Described on page 85 of Paper No. 15; results for 1897 given on pages 308–310 of the Nineteenth Annual Report, Part IV.

North Platte station on North Platte River.—Described on page 86 of Paper No. 15; results for 1897 given on page 310 of the Nineteenth Annual Report, Part IV. The observer since May 7, 1898, has been H. E. Dress.

Morrison station on Bear Creek.—Described on page 91 of Paper No. 15; results for 1897 given on page 317 of the Nineteenth Annual Report, Part IV. It is located in the upper part of the town of Morrison, Colorado, but has not been maintained in 1898, owing to the fact that the Denver Union Water Company has given a report of the discharge of the creek at their head gates, about one-half mile above the town.

Marshall station on South Boulder Creek.—Described on page 91 of Paper No. 15; results for 1897 shown on page 318 of the Nineteenth Annual Report, Part IV. The discharges of the Community, and of the South Boulder and Coal Creek ditches should be added to that of the creek in order to obtain the total discharge at this point.

Boulder station on Boulder Creek.—Described on page 92 of Paper No. 15; results for 1897 given on pages 319–320 of the Nineteenth Annual Report, Part IV.

Lyons station on St. Vrain Creek.—Described on page 93 of Paper No. 15; results for 1897 given on pages 320–321 of the Nineteenth Annual Report, Part IV. The discharge of Supply ditch should be added to that of St. Vrain Creek to obtain the total discharge of the latter.

Arkins station, on Big Thompson Creek.—Described on page 94 of Paper No. 15; results for 1897 given on pages 321–322 of the Nineteenth Annual Report, Part IV. The discharges of Home Supply and Handy ditches should be added to that of Big Thompson River to obtain total discharge of the latter.

Denver station on South Platte River.—Described on page 88 of Paper No. 15; results for 1897 given on pages 311–315 of the Nineteenth Annual Report, Part IV. Another inclined gage rod reading the same as the one on the right bank was placed on the left side in August and is now in use. It consists of a 4 by 4 inch by 12 foot timber fastened to posts driven into the left bank and graduated to vertical feet and tenths.

Orchard station on South Platte River.—Described on page 89 of Paper No. 15; results for 1897 given on pages 315–316 of the Nineteenth Annual Report, Part IV. Another rod was placed at the wagon bridge on April 24, 1898, and is now in use. It consists of a vertical 2 by 6 inch by 5 feet 4 inch timber, fastened by spikes to a pile of the bridge at about the center of the channel, on the downstream side of the bridge. The rod is marked in tenths. The new gage rod is securely fastened by means of heavy spikes driven into a pile on east side of bridge near the 300-foot mark. The channel is straight for several hundred feet above and below, but both banks are low and liable to overflow. The bed of the stream is sandy and shifting and liable to serious changes. The gagings are aken either from the lower side of the bridge or by wading. The

gage observer is still Mrs. U. E. Foley, who lives at a distance of about one-fourth mile and who reads the rod once each day.

Columbus station on Loup River.—Described on page 97 of Paper No. 15; results for 1897 given on pages 323–333 of the Nineteenth Annual Report, Part IV. No rating table was constructed for this station, there being no constant relation between discharge and gage height. The mean daily discharges were computed by the indirect method outlined in the Nineteenth Annual Report, Part IV, pages 324–333.

Columbus station on Platte River.—Described on page 98 of Paper No. 15; results for 1897 given on pages 333–334 of the Nineteenth Annual Report, Part IV. No rating table was constructed for this station, there being no constant relation between discharge and gage height. The mean daily discharges were computed by the indirect method outlined in the Nineteenth Annual Report, Part IV, pages 324–331.

Norfolk station on Elkhorn River.—Described on page 99 of Paper No. 15; results for 1897 given on pages 334–335 of the Nineteenth Annual Report, Part IV. The observer is Burr Taft. No rating table was constructed for this station, there being no constant relation between discharge and gage height. The mean daily discharges were computed by the indirect method outlined in the Nineteenth Annual Report, Part IV, pages 324–331.

TABLES OF DAILY GAGE HEIGHT.

Daily gage height, in feet, of Laramie River at Woods Landing, Wyoming, for 1898.

Day.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.
1	0.80	1.30	2.35	1.20	0.50	0.30	0.40
2	.80	1.25	2.50	1.20	.40	.30	.40
3	.80	1.20	2.55	1.10	.40	.30	.40
4	.80	1.10	2.40	1.10	.40	.30	.40
5	.80	1.00	2.45	1.00	.40	.30	.40
6	.80	1.00	2.50	1.00	.40	.30	.40
7	.80	1.05	2.45	1.00	.40	.30	.40
8	.80	1.15	2.55	.90	.40	.30	.40
9	.80	1.20	2.35	.90	.40	.30	.40
10	.80	1.30	2.20	.85	.40	.30	.40
11	.80	1.40	2.30	.80	.40	.30	.40
12	.80	1.50	2.35	.80	.40	.30	.40
13	.90	1.55	2.35	.80	.40	.30	.40
14	.95	1.70	2.60	.80	.40	.30	.40
15	1.05	2.00	2.50	.70	.40	.30	.40
16	1.00	2.20	2.50	.70	.40	.30	.40
17	1.10	2.35	2.40	.70	.40	.30	.40
18	1.05	1.90	2.40	.70	.40	.30	.40
19	.95	1.70	2.35	.70	.40	.30	.40
20	1.00	1.75	2.30	.70	.40	.30	.40
21	1.00	1.85	2.20	.70	.40	.30	.....
22	1.00	1.95	2.15	.70	.40	.30	.....
23	1.00	2.00	2.05	.60	.40	.30	.....
24	1.00	2.30	1.95	.60	.40	.30	.....
25	1.00	2.65	1.75	.60	.40	.30	.....
26	1.05	2.75	1.60	.60	.30	.30	.....
27	1.15	2.65	1.45	.50	.30	.30	.....
28	1.35	2.40	1.40	.50	.30	.30	.....
29	1.50	2.20	1.30	.50	.30	.30	.....
30	1.40	2.40	1.30	.50	.30	.30	.....
31	.....	2.45	.....	.50	.30	.....	.....

Daily gage height, in feet, of Laramie River at Uva, Wyoming, for 1898.

Day.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	1.10	1.10	3.50	1.20	0.20	0.30	0.30	.....	0.70
2	1.10	1.10	3.30	1.10	.20	.30	.30	.....	.....
3	1.20	1.20	3.10	1.10	.20	.30	.35	.....	.....
4	1.20	1.40	3.10	1.10	.20	.30	.35	.....	.....
5	1.20	1.40	3.20	1.00	.15	.30	.35	.....	.....
6	1.20	1.40	3.30	1.00	.10	.30	.30	0.40	.....
7	1.10	1.30	3.40	1.00	.20	.30	.30	.45	.....
8	1.10	1.30	3.20	.90	.20	.30	.30	.45	.80
9	1.05	1.30	3.00	1.20	.20	.30	.30	.50	.70
10	1.10	1.40	2.80	1.10	.25	.30	.35	.55	.....
11	1.40	1.30	2.80	1.00	.30	.30	.35	.60	.....
12	1.70	1.30	3.20	1.00	.30	.30	.35	.60	.....
13	1.80	1.30	3.40	1.00	.40	.30	.40	.60	.....
14	1.60	1.60	3.10	.90	.40	.35	.40	.60	.....
15	1.50	2.40	3.20	1.00	.50	.35	.40	.70	.80
16	1.50	2.10	3.40	.90	.50	.35	.40	.70	.....
17	1.50	2.00	3.30	.90	.50	.30	.40	.70	.....
18	1.40	2.00	3.20	.80	.45	.30	.45	.60	.70
19	1.40	2.20	3.10	.80	.40	.30	.45	.60	.....
20	1.20	2.60	3.00	.70	.40	.30	.45	.60	.....
21	1.20	2.70	2.90	.60	.40	.30	.40	.60	.....
22	1.20	2.40	2.80	.60	.40	.30	.40	.60	.80
23	1.10	2.50	2.60	.60	.40	.30	.40	.55	.....
24	1.10	2.80	2.40	.60	.35	.35	.40	.55	.....
25	1.10	3.00	2.20	.60	.30	.35	.40	.60	.....
26	1.10	3.10	2.00	.50	.30	.35	.35	.60	.....
27	1.10	3.40	1.90	.40	.30	.30	.35	.....	.....
28	1.10	3.80	1.70	.40	.30	.30	.35	.....	.70
29	1.10	3.80	1.50	.30	.30	.30	.30	.....	.80
30	1.10	3.70	1.30	.30	.30	.30	.....	.....	.....
31	.....	3.70	.....	.20	.30	.....	.....	.....	.....

Daily gage height, in feet, of North Platte River at Orin, Wyoming, for 1898.

Day.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	.....	.....	0.90	.....	4.63	3.45	0.85	0.35	0.68	0.85	.....
2	.....	.....	.90	3.03	4.35	3.10	.80	.35	.....	.85	.....
3	.....	.....	.90	3.10	4.25	.....	.75	.35	.....	.85	.....
4	.....	.....	.90	3.10	4.20	2.75	.75	.....	.....	.90	.....
5	.....	1.30	.90	3.25	.....	2.43	.75	.30	.....	.95	.....
6	.....	.....	.90	3.20	4.50	2.28	.75	.30	.....	.....	.....
7	.....	.....	1.03	3.13	4.55	2.20	.....	.30	.....	.....	0.85
8	.....	.....	1.08	.....	4.45	2.08	.70	.30	.....	.....	.....
9	.....	.....	1.17	3.00	4.18	1.93	.65	.30	.....	.....	.....
10	.....	.....	1.17	3.00	4.08	.....	1.15	.25	.70	.....	.....
11	.....	.....	1.25	3.00	4.00	1.83	.98	.....	.....	.....	.....
12	.....	.90	1.30	3.00	.....	1.68	.80	.20	.....	.....	.....
13	.....	.....	1.45	3.10	4.28	1.63	.88	.20	.....	.85	.....
14	.....	.....	1.80	3.25	4.30	1.80	.....	.20	.....	.....	.90
15	.....	.....	2.20	.....	4.45	2.10	.90	.20	.....	.....	.....
16	.....	.....	2.50	3.60	4.70	1.85	.80	.20	.....	.....	.....
17	.....	.....	.....	4.00	4.50	.....	.73	.20	.....	.....	.....
18	.....	.....	2.75	4.10	4.40	1.73	.70	.....	.....	.....	.....
19	.....	.75	3.00	4.05	.....	1.63	.65	.20	.75	.....	.....
20	.....	.....	3.40	4.10	4.50	1.53	.60	.20	.....	.....	.....
21	.....	.....	3.60	4.25	4.50	1.43	.....	.20	.....	.90	.95
22	.....	.....	3.60	.....	4.35	1.33	.55	.20	.....	.....	.....
23	.....	.....	3.60	4.00	4.30	1.23	.50	.20	.....	.....	.....
24	.....	.....	.....	3.95	4.15	.....	.45	.20	.65	.....	.....
25	1.70	.....	3.30	6.45	4.05	1.10	.50	.....	.....	.....	.....
26	.....	.....	3.23	6.50	.....	1.03	.50	.20	.....	.....	.....
27	.....	.....	3.05	5.65	3.93	1.00	.40	.25	.....	.....	.....
28	.....	.....	2.98	5.65	3.83	.98	.....	.38	.....	.82	.95
29	.....	.....	2.90	.....	3.73	.95	.35	.48	.....	.....	.....
30	.....	.....	2.90	5.05	3.60	.90	.35	.58	.85	.....	.....
31	.....	.....	.....	4.90	.....	.....	.35	.....	.....	.....	.....

Daily gage height, in feet, of North Platte River at Gering, Nebraska, for 1898.

Day.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.
1	1.10	1.70	2.50	1.80	0.90	0.70	0.70
2	1.10	1.60	2.40	1.70	.90	.70	.70
3	1.10	1.70	2.40	1.60	.90	.70	.70
4	1.10	1.80	2.30	1.50	.80	.70	.70
5	1.10	1.90	2.30	1.45	.80	.60	.70
6	1.20	1.80	2.20	1.50	.80	.60	.75
7	1.20	1.70	2.20	1.40	.90	.70	.75
8	1.20	1.70	2.20	1.30	.80	.70	.75
9	1.20	1.70	2.20	1.30	.80	.80	.75
10	1.20	1.70	2.10	1.30	.80	.70	.75
11	1.20	1.60	2.10	1.30	.80	.70	.80
12	1.20	1.60	2.10	1.30	.70	.70	.80
13	1.30	1.50	2.00	1.30	.70	.70	.80
14	1.30	1.50	2.10	1.40	.70	.70	.80
15	1.30	1.50	2.10	1.30	.70	.70	.80
16	1.30	1.60	2.35	1.30	.70	.70	.80
17	1.40	1.70	2.40	1.30	.80	.70	.90
18	1.40	1.80	2.40	1.30	.80	.70	.90
19	1.40	1.90	2.30	1.30	.80	.70	.90
20	1.50	1.90	2.30	1.30	.70	.70	.90
21	1.70	2.00	2.20	1.20	.80	.70	.90
22	1.80	2.00	2.10	1.10	.80	.70	.90
23	1.80	2.10	2.10	1.10	.80	.70	.90
24	1.80	2.10	2.10	1.10	.80	.70	.90
25	1.80	2.00	2.10	1.10	.70	.70	.95
26	1.80	1.90	2.00	1.10	.70	.70	.95
27	1.80	3.00	2.00	1.00	.70	.70	.90
28	1.90	2.90	2.00	1.00	.70	.70	.90
29	1.90	3.00	1.90	1.00	.70	.70	.90
30	1.90	2.80	1.80	1.00	.70	.70	.90
31	.....	2.70	.....	.95	.70	.....	.90

Daily gage height, in feet, of North Platte River at Camp Clarke, Nebraska, for 1898.

Day.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.
1	2.27	2.91	3.89	3.20	2.33	1.65	1.72
2	2.27	2.84	3.86	3.05	2.32	1.65	1.80
3	2.37	2.91	3.69	2.98	2.30	1.60	1.80
4	2.44	3.07	3.60	2.95	2.23	1.60	1.81
5	2.45	3.12	3.59	2.95	1.98	1.62	1.80
6	2.35	3.17	3.49	2.86	2.30	1.62	1.80
7	2.37	3.17	3.47	2.75	2.31	1.65	1.81
8	2.35	3.05	3.47	2.72	1.90	1.65	1.81
9	2.39	3.02	3.34	2.68	1.95	1.65	1.83
10	2.40	3.00	3.50	2.65	1.90	1.87	1.87
11	2.42	3.02	3.49	2.60	1.86	1.81	1.89
12	2.49	2.93	3.45	2.70	1.81	1.80	1.89
13	2.38	3.02	3.45	2.55	1.80	1.80	1.87
14	2.40	3.04	3.44	2.50	1.78	1.81	1.87
15	2.42	2.88	3.54	2.50	1.75	1.80	1.85
16	2.50	2.90	3.56	2.50	1.80	1.80	1.82
17	2.44	2.92	3.60	2.50	1.85	1.80	1.80
18	2.55	2.92	3.65	2.50	1.86	1.80	1.80
19	2.65	2.96	3.55	2.55	1.85	1.75	1.78
20	2.72	3.17	3.56	2.55	1.80	1.67	1.75
21	2.85	3.34	4.59	2.50	1.76	1.70	2.05
22	2.87	3.38	3.57	2.48	1.78	1.70	2.05
23	3.00	3.45	3.60	2.52	1.78	1.68	2.06
24	3.06	2.93	3.59	2.47	1.75	1.65	2.04
25	2.97	3.40	3.55	2.46	1.75	1.72	2.05
26	2.97	3.44	3.47	2.45	1.72	1.73	2.07
27	2.97	4.10	3.40	2.35	1.60	1.73	2.10
28	2.87	4.40	3.34	2.33	1.68	1.79	2.09
29	2.93	4.35	3.29	2.33	1.68	1.65	2.08
30	2.96	4.11	3.25	2.35	1.08	1.65	2.07
31	.....	3.94	.....	2.32	1.66	.....	2.10

Discontinued October 31, 1898.

Daily gage height, in feet, of North Platte River at North Platte, Nebraska, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	2.80	2.90	2.40	2.40	2.55	3.75	2.65	1.50	.35	1.20	1.70	2.20
2	2.90	2.90	2.30	2.30	2.60	3.50	2.60	1.90	.45	1.10	1.70	2.20
3	2.90	2.80	2.15	2.25	2.70	3.35	2.60	1.95	.55	1.00	1.70	2.20
4	2.80	2.90	2.15	2.15	2.70	3.30	2.70	1.75	.55	1.10	1.70	2.30
5	2.90	2.90	2.10	2.30	2.70	3.25	2.55	1.45	.65	1.10	1.80	2.30
6	2.90	2.90	2.05	2.40	2.70	3.20	2.50	1.40	.50	1.20	1.80	2.30
7	2.90	2.90	2.05	2.30	2.75	3.20	2.45	1.50	.60	1.30	1.80	2.30
8	3.00	3.00	2.15	2.35	2.70	3.10	2.25	1.40	.75	1.20	1.70	2.30
9	3.00	3.05	2.25	2.25	2.70	3.10	2.20	1.30	.90	1.35	1.80	2.30
10	2.90	3.00	2.25	2.05	2.70	3.10	2.50	1.20	1.20	1.30	1.65	2.30
11	2.90	3.05	2.25	2.15	2.60	3.10	2.30	1.15	1.35	1.30	1.70	2.50
12	2.80	3.20	2.25	2.25	2.60	3.10	3.40	1.10	1.65	1.35	1.80	2.50
13	2.85	3.20	2.20	2.30	2.55	3.05	2.10	1.00	1.50	1.30	1.80	2.50
14	2.90	3.25	2.15	2.20	2.50	3.25	2.00	.90	1.70	1.30	1.80	2.50
15	2.80	3.20	2.25	2.10	2.55	3.15	1.90	.80	1.80	1.30	1.70	2.50
16	2.85	3.05	2.15	2.20	2.65	3.05	1.80	.80	1.70	1.30	1.85	2.50
17	2.80	2.90	2.20	2.00	3.10	3.00	1.85	.80	1.65	1.30	1.80	2.50
18	2.90	2.85	2.10	2.05	2.90	3.05	1.80	.80	1.50	1.30	1.90	2.50
19	2.85	2.80	2.25	2.05	2.80	3.10	1.80	.75	1.40	1.40	2.10	2.50
20	2.80	2.80	2.25	2.15	2.80	3.15	1.70	.60	1.30	1.50	2.00	2.50
21	2.80	2.80	2.30	2.15	2.90	3.10	1.70	.60	1.25	1.50	1.85	2.60
22	2.80	2.70	2.15	2.15	2.85	3.00	1.70	.60	1.20	1.50	1.80	2.60
23	2.85	2.65	2.00	2.25	2.90	3.00	1.60	1.00	1.20	1.60	1.80	2.60
24	2.90	2.55	2.00	2.20	2.80	3.00	1.60	1.05	1.20	1.60	1.80	2.60
25	2.80	2.50	1.95	2.25	2.80	3.00	1.65	.85	1.20	1.60	1.80	2.60
26	2.90	2.45	1.90	2.35	2.90	2.90	1.60	.75	1.20	1.65	1.80	2.60
27	2.90	2.45	2.05	2.55	3.10	2.90	1.60	.70	1.20	1.70	1.80	2.70
28	2.90	2.35	2.25	2.55	3.10	2.85	1.45	.55	1.10	1.70	2.10	2.70
29	2.90	.....	2.45	2.55	3.00	2.70	1.30	.65	1.10	1.70	2.20	2.70
30	2.90	.....	2.35	2.55	3.95	2.75	1.20	.55	1.15	1.70	2.20	2.70
31	2.90	.....	2.30	.....	3.60	.....	1.40	.50	.....	1.70	.....	2.70

Daily discharge, in cubic feet per second, of Bear Creek at Morrison, Colorado, for 1898.

[Furnished by the Denver Union Water Company.]

Day.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.
1	.....	117	156	91	78	31	29
2	.....	117	156	83	57	31	29
3	60	117	151	83	47	31	26
4	73	117	151	78	47	31	26
5	78	117	151	117	47	31	26
6	78	117	156	91	44	31	26
7	91	130	156	91	44	31	23
8	104	156	182	78	44	31	23
9	117	143	182	78	44	31	23
10	117	143	182	73	57	29	23
11	130	143	182	70	55	29	26
12	143	130	195	70	55	29	26
13	143	130	208	68	52	29	26
14	130	182	182	68	47	29	23
15	130	156	169	68	47	29	23
16	130	156	156	57	47	29	a 20
17	130	156	156	52	47	28	20
18	130	156	143	52	47	28	20
19	130	156	143	47	44	28	20
20	130	156	143	47	44	28	20
21	130	156	143	47	44	29	20
22	130	156	130	47	42	29	20
23	117	151	130	78	42	29	20
24	117	151	130	65	39	29	20
25	117	151	130	65	39	29	20
26	117	151	130	60	37	29	20
27	117	148	130	57	31	29	20
28	130	146	117	57	34	29	20
29	130	146	104	52	31	29	20
30	117	146	104	50	31	29	20
31	117	.....	91	47	.....	29	.....

a Approximated after November 15; no reports sent in.

Daily gage height, in feet, of South Boulder Creek at Marshall, Colorado, for 1898.

Day.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.
1	1.05	2.15	2.15	1.30	1.20	.75	.90
2	1.15	2.30	2.10	1.25	1.15	.70	.85
3	1.30	2.50	1.95	1.25	1.05	.80	.85
4	1.25	2.45	1.85	1.20	.95	.80	.90
5	1.35	2.25	1.85	1.20	.95	.85	.90
6	1.55	2.10	1.80	1.30	.95	.85	.90
7	1.70	2.15	1.80	1.25	.90	.75	.90
8	1.80	2.20	1.85	1.25	.90	.75	.90
9	2.05	2.20	1.85	1.20	.90	.80	.80
10	2.15	2.15	1.85	1.20	.90	.80	.85
11	2.20	2.25	1.90	1.20	.80	.80	.95
12	2.30	2.35	1.85	1.15	.90	.85	.90
13	2.20	2.35	2.05	1.15	.85	.90	.90
14	2.15	2.60	1.95	1.15	.85	.90	.85
15	2.15	2.55	1.80	1.15	.95	.90	.80
16	2.15	2.50	1.75	1.40	.95	.85	.75
17	2.15	2.65	1.70	.95	.90	.80	.70
18	2.15	2.55	1.70	.90	.80	.80	.70
19	2.05	2.60	1.65	1.05	.85	.85	.70
20	2.00	2.55	1.65	1.10	.85	.90	.70
21	2.00	2.55	1.60	.85	.80	.90	.75
22	1.85	2.45	1.60	.90	.80	1.00	.80
23	1.85	2.45	1.55	.85	.85	1.00	.80
24	2.05	2.25	1.55	.95	.85	1.00	.85
25	2.15	2.20	1.45	1.00	.85	1.00	.85
26	2.10	2.15	1.40	1.00	.85	1.00	.85
27	2.15	2.25	1.40	1.00	.80	.90	.90
28	2.25	2.15	1.35	1.00	.80	.90	.90
29	2.25	2.15	1.30	1.00	.75	.90	.90
30	2.30	2.10	1.30	.95	.75	.90	.85
31	2.25	.....	1.30	.95	.....	.90	.....

Daily gage height, in feet, of Boulder Creek at Boulder, Colorado, for 1898.

Day.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.
1	0.92	1.80	1.80	0.92	0.95	0.25	0.25
2	.93	1.85	1.78	.90	.98	.30	.22
3	.92	2.00	1.68	.92	.98	.28	.28
4	.90	2.03	1.60	.95	.90	.30	.25
5	.95	1.85	1.50	.98	.75	.30	.22
6	.95	1.68	1.52	1.30	.65	.50	.28
7	1.15	1.72	1.38	1.15	.63	.35	.25
8	1.40	1.85	1.52	1.03	.60	.33	.30
9	1.48	1.90	1.52	.93	.55	.30	.32
10	1.60	1.90	1.55	.83	.65	.30	.42
11	1.67	1.95	1.73	.78	.70	.28	.85
12	1.70	2.05	1.65	.73	.65	.25	1.05
13	1.65	2.35	1.60	.70	.62	.28	.85
14	1.60	2.43	1.58	.73	.60	.30	.65
15	1.57	2.43	1.53	.73	.55	.30	.78
16	1.60	2.43	1.50	.73	.53	.25	.82
17	1.62	2.40	1.43	.68	.50	.20	1.00
18	1.53	2.43	1.38	.65	.50	.23	1.15
19	1.42	2.43	1.35	.63	.45	.33	1.12
20	1.33	2.28	1.33	.63	.40	.38	1.00
21	1.20	2.20	1.28	.75	.48	.30	.92
22	1.22	2.23	1.15	.82	.45	.33	.88
23	1.30	2.25	1.08	.85	.40	.35	.70
24	1.42	2.28	1.08	.78	.33	.38	.60
25	1.60	2.20	1.05	.75	.30	.35	.62
26	1.68	2.08	1.02	.70	.28	.30	.65
27	1.78	1.95	1.02	.65	.28	.28	.50
28	1.85	1.93	.98	.63	.28	.25	.32
29	1.93	1.83	.95	.60	.28	.23	.25
30	1.83	1.88	.90	.60	.25	.22	.20
31	1.85	.....	.92	.78	.....	.22	.....

Daily gage height, in feet, of St. Vrain Creek at Lyons, Colorado, for 1898.

Day.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.
1	1.98	2.90	3.10	2.15	2.30	1.80	1.90
2	2.25	3.20	3.15	2.00	2.35	1.80	1.90
3	1.96	3.50	3.05	2.10	2.30	1.80	1.90
4	2.00	3.45	3.10	2.05	2.30	1.80	1.90
5	2.05	2.95	3.15	2.45	2.25	1.80	1.90
6	2.25	2.85	3.05	2.40	2.15	1.80	1.90
7	2.55	3.10	3.10	2.40	2.15	1.80	1.90
8	2.72	3.40	3.00	2.35	2.10	1.80	1.80
9	2.92	3.45	3.10	2.30	2.10	1.80	1.80
10	3.05	3.45	2.95	2.20	2.20	1.80	1.80
11	3.05	3.55	3.30	2.20	2.20	1.80	1.80
12	3.15	3.60	3.30	2.25	2.20	1.80	1.80
13	3.00	3.75	3.00	2.20	2.20	1.80	1.80
14	2.90	3.90	2.95	2.30	2.10	1.80	1.80
15	2.95	3.90	2.85	2.25	2.10	1.80	1.80
16	2.90	3.85	2.80	2.20	2.10	1.80	1.80
17	2.95	4.00	2.75	2.35	2.00	1.90	1.90
18	2.70	3.85	2.65	2.25	2.00	1.90	1.90
19	2.70	3.85	2.55	2.30	2.00	1.90	1.90
20	2.55	3.90	2.45	2.30	2.00	1.90	1.80
21	2.50	3.90	2.45	2.30	2.00	1.90	1.70
22	2.50	3.90	2.35	2.25	2.00	1.90	1.70
23	2.45	3.80	2.45	2.30	1.90	1.80	1.70
24	2.55	3.95	2.50	2.30	1.90	1.80	1.65
25	2.75	3.70	2.55	2.30	1.80	1.80	1.60
26	2.90	3.60	2.45	2.25	1.80	1.80	1.60
27	2.70	3.30	2.45	2.25	1.80	1.85	1.60
28	3.10	3.15	2.15	2.20	1.90	1.90	1.60
29	3.05	3.15	2.10	2.20	1.90	1.90	1.70
30	2.85	3.10	2.15	2.20	1.90	1.90	1.70
31	3.00	.....	2.20	2.20	.....	1.90	.....

Daily gage height, in feet, of Big Thompson Creek at Arkins, Colorado, for 1898.

Day.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.
1	0.45	1.30	1.40	1.00	0.75	0.30	0.10
2	.35	1.55	1.35	.75	.75	.20	.10
3	.30	1.60	1.25	.80	.75	.30	.10
4	.35	1.60	1.20	.70	.50	.35	.20
5	.25	1.40	1.05	.65	.50	.25	.15
6	.35	1.35	1.05	.80	.50	.30	.15
7	.45	1.50	1.20	.85	.55	.30	.35
8	.50	1.55	1.20	.85	.55	.35	.25
9	.75	1.60	1.20	.80	.50	.30	.10
10	.95	1.55	1.25	.70	.50	.30	.10
11	1.15	1.60	1.25	.60	.50	.30	.10
12	1.10	.70	1.30	.60	.50	.30	.10
13	1.10	.85	1.60	.65	.50	.25	.10
14	1.10	.95	1.50	.65	.65	.25	.10
15	1.10	1.20	1.40	.60	.60	.25	.10
16	1.20	1.20	1.40	.60	.30	.20	.10
17	1.20	1.25	1.35	.65	.30	.25	.10
18	1.10	1.40	1.30	.70	.25	.30	.10
19	.85	1.95	1.20	.60	.25	.20	.10
20	.85	1.75	1.05	.60	.25	.25	.10
21	.75	1.65	1.00	.60	.20	.25	.10
22	.70	1.80	.90	.65	.25	.15	.10
23	.85	1.95	.90	.60	.20	.20	.10
24	.95	2.00	.90	.65	.20	.10	.15
25	1.20	1.85	.90	.60	.25	.10	.20
26	1.20	1.60	.85	.60	.20	.15	.30
27	1.25	1.45	.90	.60	.20	.25	.30
28	1.30	1.35	.80	.50	.20	.10	.30
29	1.40	1.35	.75	.55	.25	.10	.35
30	1.35	1.35	.70	.50	.25	.10	.35
31	1.35	.....	.80	.50	.....	.10	.....

Daily gage height, in feet, of South Platte River at Fifteenth Street Bridge, Denver, Colorado, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	5.45	5.40	5.10	4.80	6.00	7.05	5.30	5.40	5.35	5.30	5.25	5.15
2	5.40	5.30	5.05	4.80	6.20	7.00	5.55	5.35	5.40	5.20	5.30	5.05
3	5.35	5.40	5.00	4.85	6.30	7.25	5.60	5.40	5.40	5.15	5.30	5.05
4	5.30	5.50	4.95	5.05	6.35	7.45	5.70	5.30	5.35	5.25	5.25	5.10
5	5.40	5.40	5.00	5.25	6.45	7.35	5.85	5.50	5.25	5.35	5.30	5.00
6	5.60	5.20	5.05	5.40	6.75	7.35	6.05	6.20	5.40	5.25	5.30	5.10
7	5.60	5.10	5.15	5.35	6.80	7.05	6.25	6.40	5.30	5.15	5.30	5.00
8	5.70	5.20	5.20	5.40	7.35	7.00	6.30	6.30	5.20	5.10	5.25	5.10
9	5.55	5.20	5.25	5.45	7.65	7.55	6.60	6.30	5.25	5.05	5.30	5.10
10	5.50	5.10	5.30	5.50	7.55	7.50	6.35	6.20	5.30	5.00	5.20	5.10
11	5.45	5.20	5.15	5.55	7.45	7.55	6.50	6.00	5.25	4.95	5.10	5.00
12	5.40	5.30	5.10	6.30	7.40	7.00	6.45	5.70	5.20	4.90	5.20	5.10
13	5.35	5.30	4.95	6.00	7.25	7.55	7.15	5.80	5.65	4.95	4.95	5.20
14	5.30	5.35	5.05	5.90	7.10	7.50	7.35	5.70	5.45	4.90	4.90	5.30
15	5.25	5.40	5.20	6.15	7.05	7.45	7.25	5.60	5.30	4.95	4.95	5.20
16	5.25	5.35	5.35	6.20	6.95	7.45	6.95	5.55	5.30	5.05	5.05	5.20
17	5.25	5.25	5.30	6.10	6.80	7.40	6.75	5.65	5.35	5.45	5.45	5.10
18	5.20	5.10	5.25	6.20	6.80	7.35	6.55	5.55	5.40	5.50	5.50	5.10
19	5.10	5.00	5.20	6.15	7.00	7.25	6.50	5.45	5.50	5.35	5.45	5.10
20	5.05	5.05	5.25	6.10	7.00	7.20	6.35	5.35	5.45	5.35	4.90	5.00
21	4.95	5.15	5.25	6.05	7.00	7.10	6.15	5.35	5.45	5.30	4.95	5.00
22	4.90	5.25	5.20	5.95	7.00	7.05	6.10	5.40	5.30	5.35	5.00	4.90
23	4.90	5.40	5.15	6.30	7.00	7.00	5.85	5.50	5.25	5.40	4.95	4.80
24	4.90	5.35	5.15	6.05	7.00	6.95	5.65	5.60	5.30	5.35	5.00	4.90
25	4.90	5.20	5.25	5.70	7.25	6.90	5.50	5.50	5.40	5.25	4.90	5.00
26	5.00	5.15	5.30	5.60	7.55	6.80	5.60	5.40	5.40	5.20	5.00	5.00
27	5.00	5.10	5.15	5.60	7.75	6.60	5.55	5.35	5.35	5.30	5.05	4.90
28	5.10	5.05	4.95	5.55	7.95	6.35	5.45	5.50	5.35	5.30	5.10	4.80
29	5.20	.....	4.80	5.55	7.40	6.10	5.40	5.40	5.40	5.30	5.20	4.90
30	5.30	.....	4.90	5.50	7.10	5.65	5.35	5.35	5.35	5.30	5.25	4.80
31	5.30	.....	4.85	.....	7.10	.....	5.40	5.40	.....	5.30	.....	4.80

Daily gage height, in feet, of South Platte River at Orchard, Colorado, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	4.50	4.25	3.60	3.70	2.10	4.00	2.40	2.20	2.20	2.40	2.90	4.50
2	4.45	4.20	3.60	3.65	2.20	3.90	2.40	2.20	2.20	2.40	2.90	4.50
3	4.40	4.20	3.60	3.65	2.30	3.70	2.40	2.20	2.20	2.40	2.85	4.50
4	4.45	4.20	3.60	3.65	3.00	3.50	2.40	2.20	2.20	2.40	2.85	4.50
5	4.50	4.20	3.60	3.65	3.50	3.50	2.40	2.20	2.20	2.45	2.80	4.50
6	4.40	4.10	3.60	3.60	3.70	3.70	2.40	2.20	2.20	2.45	2.80	4.50
7	4.50	4.05	3.60	3.60	4.00	3.50	2.40	2.20	2.20	2.50	2.80	4.50
8	4.50	4.10	3.60	3.65	3.70	3.30	2.40	2.20	2.20	2.50	2.85	4.50
9	4.50	4.05	3.60	3.65	3.90	3.40	2.20	2.20	2.20	2.50	2.85	4.00
10	4.40	4.00	3.60	3.60	4.00	3.50	2.20	2.20	2.20	2.50	2.90	4.00
11	4.30	3.95	3.60	3.60	4.30	3.50	2.30	2.20	2.25	2.60	3.10	4.00
12	4.20	3.90	3.60	3.60	4.20	3.40	2.70	2.20	2.30	2.60	3.00	4.00
13	4.10	3.90	3.60	3.60	4.25	3.30	3.00	2.20	2.40	2.60	3.00	4.00
14	4.05	3.80	3.60	3.60	4.30	3.30	3.20	2.20	2.40	2.60	3.10	4.00
15	4.00	3.85	3.60	3.60	4.30	3.40	3.30	2.20	2.40	2.60	3.10	4.30
16	4.00	3.90	3.60	3.60	4.25	3.30	3.20	2.20	2.35	2.60	3.20	4.40
17	4.00	3.85	3.60	3.60	4.20	3.40	3.00	2.20	2.35	2.60	3.20	4.50
18	4.20	3.80	3.60	3.55	4.10	3.30	2.80	2.20	2.30	2.60	3.10	4 50
19	4.30	3.85	3.60	3.80	4.00	3.00	2.70	2.20	2.30	2.60	3.20	4.40
20	4.20	3.70	3.60	3.00	4.00	3.00	2.60	2.20	2.30	2.65	3.20	4.40
21	4.10	3.70	3.65	2.90	4.00	3.00	2.50	2.20	2.30	2.65	3.30	4.35
22	4.00	3.70	3.70	2.90	3.90	2.80	2.20	2.20	2.30	2.70	3.30	4.30
23	4.00	3.70	3.75	2.90	3.80	2.60	2.20	2.20	2.30	2.70	3.30	4.30
24	3.85	3.70	3.75	2.20	3.80	2.60	2.20	2.20	2.30	2.75	3.50	4.25
25	3.70	3.70	3.80	2.25	3.80	2.60	2.20	2.20	2.30	2.80	3.70	4.20
26	3.65	3.70	3.80	2.10	3.80	2.60	2.20	2.20	2.30	2.80	3.80	4.20
27	3.60	3.60	3.80	2.10	4.40	2.60	2.20	2.20	2.30	2.85	4.00	4.20
28	3.80	3.55	3.80	2.10	4.30	2.60	2.20	2.20	2.30	2.90	4.00	4.20
29	4.00	.....	3.75	2.10	4.60	2.00	2.20	2.20	2.35	3.00	4.00	4.20
30	4.20	.....	3.75	2.10	4.50	2.00	2.20	2.20	2.35	2.95	4.50	4.30
31	4.30	.....	3.70	.....	4.20	.....	2.20	2.20	.....	2.95	.....	4.30

Daily gage height, in feet, of Loup River at Columbus, Nebraska, for 1898.

Day.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.
1	4.51	4.78	5.00	4.64	4.20	4.37	4.56	4.90
2	4.77	4.77	4.95	4.64	4.24	4.34	4.58	4.85
3	4.75	4.86	5.02	4.60	4.28	4.30	4.59	4.80
4	4.77	5.07	5.14	4.62	4.63	4.31	4.66	4.75
5	4.79	5.33	5.66	4.83	4.95	4.30	4.63	4.75
6	4.82	5.28	5.95	4.88	5.24	4.30	4.64	4.80
7	4.86	5.25	5.68	4.83	5.16	4.30	4.67	4.80
8	4.81	5.22	5.63	4.83	4.97	4.32	4.67	4.85
9	4.76	5.18	5.54	4.74	4.85	4.31	4.72	4.90
10	4.80	5.16	5.46	4.66	4.77	4.36	4.74	4.90
11	4.79	5.19	5.35	4.68	4.68	4.42	4.84	4.94
12	4.86	5.19	5.26	4.65	4.64	4.48	4.97	4.90
13	4.83	5.16	5.32	4.66	4.61	4.82	4.90	.....
14	5.06	5.07	5.36	4.67	4.58	5.03	4.82	.....
15	5.02	4.91	5.42	4.66	4.57	4.93	4.78	.....
16	4.96	4.95	5.36	4.65	4.59	4.89	4.76	.....
17	4.83	4.96	5.35	4.62	4.67	4.85	4.76	.....
18	4.77	5.15	5.30	4.54	4.83	4.81	4.77	.....
19	4.86	5.19	5.30	4.49	4.78	4.80	4.86	.....
20	4.96	5.18	5.33	4.44	4.66	4.73	4.92	.....
21	4.87	5.41	5.40	4.43	4.63	4.65	4.86	.....
22	4.75	5.44	5.50	4.41	4.65	4.49	4.82	.....
23	4.71	5.48	5.39	4.45	4.63	4.41	4.80	.....
24	4.73	5.68	5.00	4.35	4.62	4.50	4.85	.....
25	4.77	5.40	4.77	4.31	4.62	4.57	4.90	.....
26	4.85	5.64	4.71	4.30	4.63	4.58	4.80	.....
27	4.83	5.46	4.68	4.30	4.63	4.57	4.90	.....
28	4.83	5.34	4.67	4.28	4.56	4.56	4.90	.....
29	4.87	5.11	4.65	4.26	4.45	4.56	4.85	.....
30	4.81	5.10	4.66	4.26	4.41	4.56	4.80	.....
31	.....	4.98	.....	4.22	4.39	.....	4.95	.....

Daily gage height, in feet, of Platte River at Columbus, Nebraska, for 1898.

Day.	Apr.	May.	June.	July.	Day.	Apr.	May.	June.	July.	Day.	Apr.	May.	June.	July.
1	.....	2.50	3.90	3.60	12	.....	3.45	4.35	2.80	23	2.25	3.98	3.50	(a)
2	.....	2.80	5.10	3.40	13	.....	3.34	4.28	2.60	24	2.10	4.12	3.60	(a)
3	.....	3.22	4.50	3.42	14	.....	3.27	4.22	2.55	25	2.00	3.98	3.60	(a)
4	.....	3.40	5.00	3.45	15	.....	3.24	4.15	2.50	26	2.06	3.85	3.50	(a)
5	.....	3.70	4.90	3.40	16	.....	3.27	4.35	2.55	27	1.97	4.04	3.40	(a)
6	.....	3.75	4.72	3.38	17	2.36	3.34	4.20	2.50	28	1.95	3.93	3.42	(a)
7	.....	3.80	4.85	3.20	18	2.42	3.50	4.05	2.45	29	1.95	3.75	3.45	(a)
8	.....	3.70	4.65	3.15	19	2.55	3.28	3.96	2.20	30	2.60	3.85	3.50	(a)
9	.....	3.56	4.45	3.20	20	2.60	3.90	3.78	2.00	31	.....	4.03	.....	(a)
10	.....	3.55	4.52	3.00	21	2.65	4.30	3.56	(a)					
11	.....	3.35	4.48	2.90	22	2.40	4.10	3.58	(a)					

a River dry.

Daily gage height, in feet, of Elkhorn River at Norfolk, Nebraska, for 1898.

Day.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.
1	1.66	1.53	2.64	1.75	1.03	1.08	.93	1.37
2	1.65	1.53	2.53	1.73	1.03	1.00	.99	1.35
3	1.65	1.66	2.40	1.53	1.02	1.00	1.03	1.35
4	1.64	1.67	2.77	1.66	1.02	1.00	1.03	1.35
5	1.63	1.76	4.44	1.67	1.01	.98	1.04	1.35
6	1.63	1.82	4.70	1.66	1.02	.98	1.02	1.35
7	1.57	1.93	3.62	1.67	1.03	.97	1.02	1.35
8	1.58	1.87	3.36	1.71	1.33	.98	1.02	1.36
9	1.56	1.95	3.28	1.68	1.36	1.01	1.03	1.33
10	1.55	1.97	3.78	1.65	1.56	1.05	1.04	1.33
11	1.55	1.90	3.47	1.63	1.60	1.03	1.15	1.34
12	1.59	1.84	3.15	1.57	1.70	1.17	1.17	1.34
13	1.61	1.82	3.00	1.55	1.56	1.18	1.18	1.34
14	1.61	1.87	2.92	1.49	1.56	1.14	1.18	1.39
15	1.60	1.96	2.77	1.45	1.49	1.15	1.19	1.42
16	1.60	1.85	2.67	1.48	1.44	1.13	1.13	1.42
17	1.59	1.86	2.62	1.28	1.42	1.13	1.23	1.43
18	1.61	2.06	2.58	1.26	1.37	1.13	1.28	1.41
19	1.63	2.08	2.52	1.26	1.39	1.19	1.30	1.43
20	1.65	2.68	2.54	1.18	1.42	1.07	1.33	1.50
21	1.64	2.69	2.49	1.10	1.37	1.03	1.30	1.65
22	1.60	2.65	2.34	1.13	1.21	.96	1.32	1.72
23	1.60	2.56	2.25	1.10	1.22	.98	1.33	1.76
24	1.60	2.63	2.15	1.10	1.26	1.02	1.37	1.80
25	1.57	3.23	2.13	1.13	1.27	1.03	1.36	1.80
26	1.53	3.13	2.10	1.03	1.24	1.01	1.36	1.80
27	1.52	3.10	2.04	1.01	1.24	1.12	1.39	1.87
28	1.49	3.02	1.96	1.00	1.24	.97	1.38	1.87
29	1.47	2.99	1.91	.98	1.22	.97	1.38	1.87
30	1.52	2.89	1.85	1.03	1.16	.97	1.37	1.87
31	.....	2.72	.....	1.07	1.15	.....	1.37	.....

List of discharge measurements, 1898.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
				Feet.	*Sec.-feet.*
Apr. 30	Laramie River	Woods Landing, Wyo.	C. T. Johnston	1.40	382
May 22	do	do	do	2.00	758
June 4[a]	do	do	do	2.30	1,017
Do.[b]	do	do	do	2.40	1,123
June 5	do	do	do	2.10	823
Apr. 23	do	Uva, Wyo.	do	1.10	60
May 12	do	do	do	1.40	87
May 27	do	do	do	3.50	1,007
June 8	do	do	do	3.20	819
June 22	do	do	do	2.95	682
Apr. 21	North Platte River	Orin Junction, Wyo.	do	3.45	3,924
May 10	do	do	do	3.00	2,565
May 26	do	do	do	6.30	14,972
June 8	do	do	do	4.50	6,950
June 21	do	do	do	4.50	6,977
July 2	do	do	do	3.10	2,688
May 13	do	Gering, Nebr.	Robt. H. Willis	1.50	3,572
June 6	do	do	do	2.20	9,317
June 22	do	do	do	2.20	8,751
July 2	do	do	do	1.70	5,237
May 6	do	Camp Clarke, Nebr.	do	3.17	4,541
May 24	do	do	do	3.45	6,170
June 8	do	do	do	3.54	7,553
June 17	do	do	do	3.61	7,891
June 29	do	do	do	3.30	5,171
Sept. 28	do	do	do	1.79	150
Apr. 15	do	North Platte, Nebr.	Charles P. Ross	2.10	1,844
May 2	do	do	do	2.60	4,429
May 14	do	do	do	2.50	4,288
May 23	do	do	do	2.90	5,296
May 31	do	do	do	3.60	10,074
June 4	do	do	do	3.25	8,270
June 23	do	do	do	3.00	5,848
July 22	do	do	do	1.70	697
July 30	do	do	do	1.20	324
Aug. 15	do	do	do	.80	241
Aug. 23	do	do	do	1.00	197
Sept. 9	do	do	do	.90	219
Sept. 27	do	do	do	1.20	364
Oct. 11	do	do	do	1.30	306
Oct. 26	do	do	do	1.65	801
Nov. 7	do	do	do	1.80	1,014
Apr. 22	Bear Creek	Morrison, Colo	A. L. Fellows	2.26	1
Apr. 23	South Boulder Creek.	Marshall, Colo.	do	1.35	72
May 29	do	do	do	2.29	[c]274
July 11	do	do	do	1.70	130
Aug. 6	do	do	do	1.15	47
Oct. 10	do	do	do	.55	2
Apr. 17	Boulder Creek	Boulder, Colo.	do	.78	69
May 28	do	do	do	1.85	357
July 16	do	do	J. E. Field	1.50	286
Aug. 8	do	do	A. L. Fellows	.86	62
Oct. 11	do	do	do	.28	12
May 27	St. Vrain Creek	Lyons, Colo.	do	2.80	256
July 12	do	do	do	3.10	308
Aug. 5	do	do	do	2.20	73
Oct. 12	do	do	do	1.85	20
May 26	Big Thompson Creek.	Arkins, Colo.	do	1.25	263
July 13	do	do	do	1.60	444
Aug. 4	do	do	do	.70	87
Oct. 14	do	do	do	.40	30
Apr. 21	South Platte River	Denver, Colo	do	5.90	564
July 6	do	do	do	6.10	443
Sept. 2	do	do	do	5.50	195
Oct. 8	do	do	do	5.00	90
Oct. 29	do	do	F. Cogswell	5.32	234
Apr. 24	do	Orchard, Colo	A. L. Fellows	2.20	71
May 30	do	do	do	4.60	3,214
July 9	do	do	do	2.25	32
Aug. 9	do	do	do	2.25	36
Nov. 6	do	do	F. Cogswell	2.80	302
Nov. 17	do	do	do	3.15	491

[a] 6 a. m. [b] 7.30 p. m.

[c] South Boulder and Coal Creek ditch, gage height 0.9 feet, discharge 21 second-feet; Community ditch, gage height 2.00 feet, discharge 84 second-feet.

List of discharge measurements, 1898—Continued.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
				Feet.	*Sec.-feet.*
Apr. 17	Loup River	Columbus, Nebr.	Glenn E. Smith	4.80	2,730
May 8	do	do	do	5.15	3,231
May 19	do	do	do	5.20	3,542
May 29	do	do	do	5.05	3,337
June 8	do	do	do	5.50	5,181
June 19	do	do	O. V. P. Stout	5.03	3,284
July 10	do	do	Glenn E. Smith	4.60	1,900
July 22	do	do	do	4.40	1,691
July 31	do	do	do	4.15	1,560
Aug. 21	do	do	Adna Dobson	4.65	2,542
Sept. 4	do	do	do	4.20	1,389
Sept. 17	do	do	do	4.81	2,448
Sept. 25	do	do	do	4.59	2,117
Oct. 16	do	do	do	4.76	2,381
Oct. 30	do	do	do	4.80	2,519
Nov. 20	do	do	Glenn E. Smith	4.90	2,862
Apr. 17	Platte River	do	do	2.37	1,994
May 9	do	do	do	3.65	5,612
May 19	do	do	do	3.33	3,619
May 29	do	do	do	3.82	7,104
June 8	do	do	do	4.69	16,543
June 19	do	do	O. V. P. Stout	3.95	9,123
July 10	do	do	Glenn E. Smith	3.00	3,006
July 29	do	do	do	(*a*)	285
July 31	do	do	do	(*a*)	45
Aug. 21	Main channel		Adna Dobson		(*b*)
	Middle channel		do		½
	South channel		do		2
Sept. 4	Main channel		do		(*b*)
	Middle channel		do		(*b*)
	South channel		do		2
Sept. 18	Main channel		do		(*b*)
	Middle channel		do		6
	South channel		do		4
Oct. 16	Main channel		do		(*b*)
	Middle channel		do		6
	South channel		do		8
Oct. 30	Main channel		do		(*b*)
	Middle channel		do		5
	South channel		do		8
Nov. 11	Main channel		Glenn E. Smith		(*b*)
	Middle channel		do		6
	South channel		do		10
Nov. 20	Main channel		do		(*b*)
	Middle channel		do		10
	South channel		do		15
Apr. 24	Elkhorn River	Norfolk, Nebr	do	1.60	451
May 12	do	do	do	1.84	493
May 23	do	do	do	2.56	782
June 10	do	do	do	2.86	1,319
June 20	do	do	O. V. P. Stout	2.46	760
July 28	do	do	Glenn E. Smith	1.05	228
Aug. 20	do	do	do	1.28	288
Sept. 10	do	do	do	1.00	175
Sept. 27	do	do	do	1.00	205
Oct. 22	do	do	do	1.34	256
Oct. 28	do	do	do	1.40	287
Nov. 16	do	do	do	1.40	330
Dec. 16	do	do	do	Frozen	216
Dec. 27	do	do	do	do	217
May 10	North Fork of Elkhorn River.	do	do		109
July 28	do	do	do		63
Aug. 20	do	do	do		87
Sept. 10	do	do	do		97
Sept. 27	do	do	do		79
Oct. 28	do	do	do		98
Nov. 16	do	do	do		104
Dec. 27	do	do	do		106

a Gage out of water. *b* Dry.

List of miscellaneous discharge measurements, 1898.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
				Feet.	*Sec.-feet.*
Apr. 23	Beaver River	Albion, Nebr	Glenn E. Smith		89
Apr. 26	Niobrara River	Lavaca, Nebr	do		210
Apr. 27	White River	Crawford, Nebr	do		18
Do.	do	do	do		11
Do.	Soldier Creek	do	do		4
Do.	Fort Ditch	Fort Robinson, Nebr	do		2
Apr. 28	Middle Loup River	Dunning, Nebr	do		410
Do.	do	Seneca, Nebr	do		222
Do.	Dismal River	Dunning, Nebr	do		389
May 13	Minnechadusa River	Valentine, Nebr	do		23
May 24	do	do	do		89
May 26	Elkhorn River	Arlington, Nebr	do		1,808
June 11	do	O'Neill, Nebr	do		288
June 12	Minnechadusa River	Valentine, Nebr	do		53
July 7	Frenchman River	Palisade, Nebr	do		33
Do.	Stinking Water River	do	do		24
July 27	Minnechadusa River	Valentine, Nebr	do		15
Aug. 21	Long Pine River	Long Pine, Nebr	do		44
Do.	Minnechadusa River	Valentine, Nebr	do		18
Sept. 7	do	do	do		19
Sept. 8	Plum Creek	Johnstown, Nebr	do		10
Sept. 9	Elk Creek	Bassett, Nebr	do		2
Sept. 10	Bone Creek	Long Pine, Nebr	do		14
Sept. 26	Minnechadusa River	Valentine, Nebr	do		22
Oct. 15	do	do	do		23
Oct. 29	do	do	do		27
Oct. 30	Niobrara River	Lavaca, Nebr	do		203
Oct. 31	White River	Crawford, Nebr	do		13
Do.	do	6 miles west of Crawford, Nebr.	do		21
Do.	Soldier Creek	Fort Robinson, Nebr	do		4
Do.	Niobrara River	Marsoland, Nebr	do		23
Nov. 1	Dismal River	Dunning, Nebr	do		351
Do.	Middle Loup River	do	do		433
Do.	do	Seneca, Nebr	do		198
Nov. 2	Platte River	Grand Island, Nebr	do		(a)
Nov. 17	Minnechadusa River	Valentine, Nebr	do		21
Dec. 15	Elkhorn River	Arlington, Nebr	do		422
Dec. 17	Minnechadusa River	Valentine, Nebr	do		23
Dec. 28	do	do	do		30

a Dry.

NOTE.—Additional measurements will be given in the Twentieth Annual Report, Part IV.

Rating tables.

Woods Landing.		Uva.		Orin.		Gering.		Camp Clarke.		North Platte.	
Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*
0.4	45	0.5	5	0.0	300	0.6	50	1.6	60	0.3	43
.5	50	.6	10	.2	370	.7	100	1.7	105	.4	60
.6	60	.7	15	.4	450	.8	200	1.8	150	.5	80
.7	70	.8	21	.6	550	.9	350	1.9	230	.6	100
.8	85	.9	30	.8	650	1.0	650	2.0	325	.7	140
.9	100	1.0	40	1.0	750	1.1	1,000	2.1	425	.8	179
1.0	125	1.1	50	1.2	850	1.2	1,450	2.2	570	.9	219
1.1	155	1.2	62	1.4	950	1.3	2,000	2.3	725	1.0	254
1.2	200	1.3	80	1.6	1,050	1.4	2,700	2.4	950	1.2	324
1.3	245	1.4	100	1.8	1,150	1.5	3,400	2.5	1,200	1.4	473
1.4	290	1.5	120	2.0	1,300	1.6	4,100	2.6	1,500	1.6	622
1.5	350	1.6	140	2.2	1,450	1.7	4,900	2.7	1,800	1.8	984
1.6	410	1.7	160	2.4	1,675	1.8	5,700	2.8	2,200	2.0	1,557
1.7	475	1.8	190	2.6	1,930	1.9	6,500	2.9	2,600	2.2	1,275
1.8	550	1.9	220	2.8	2,220	2.0	7,400	3.0	3,050	2.4	3,138
1.9	630	2.0	260	3.0	2,550	2.1	8,300	3.1	3,600	2.6	4,001
2.0	710	2.2	340	3.2	2,935	2.2	9,200	3.2	4,200	2.8	4,864
2.1	825	2.4	425	3.4	3,390	2.3	10,100	3.3	4,900	3.0	5,848
2.2	940	2.6	520	3.6	3,895	2.4	11,100	3.4	5,900	3.2	7,786
2.3	1,055	2.8	620	3.8	4,465	2.5	12,150	3.5	6,900	3.4	9,043
2.4	1,170	3.0	720	4.0	5,090	2.6	13,300	3.6	7,900	3.6	10,074
2.5	1,285	3.2	820	4.5	7,000	2.7	14,500	3.7	8,900	3.8	12,687
2.6	1,400	3.4	920	5.0	9,200	2.8	15,700	3.8	9,900	4.0	15,300
2.7	1,515	3.6	1,040	5.5	11,400	2.9	17,100	3 9	10,900	.....	.....
2.8	1,630	3.8	1,220	6.0	13,600	3.0	18,500	4.0	12,000	.....	.....
2.9	1,745	4.0	1,400	6.5	15,870	.....	.....	4.1	13,300	.....	.....
3.0	1,860	4.5	1,850	7.0	18,220	.....	.....	4.2	14,600	.....	.....
3.5	2,435	5.0	2,300	.....	.....	.....	.....	4.3	15,900	.....	.....
4.0	3,300	5.5	2,750	.....	.....	.....	.....	4.4	17,200	.....	.....

Rating tables—Continued.

Marshall.		Boulder.		Lyons.		Arkins.		Denver.		Orchard.a	
Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*
0.5	1	0.2	3	2.0	40	0.2	8	4.8	50	2.0	0
.6	4	.3	7	2.1	64	.3	18	4.9	69	2.1	10
.7	9	.4	13	2.2	89	.4	30	5.0	90	2.2	40
.8	15	.5	20	2.3	115	.5	45	5.1	113	2.3	75
.9	22	.6	29	2.4	141	.6	63	5.2	139	2.4	113
1.0	31	.7	41	2.5	166	.7	85	5.3	168	2.5	153
1.1	41	.8	56	2.6	192	.8	111	5.4	201	2.6	195
1.2	52	.9	75	2.7	218	.9	142	5.5	239	2.7	240
1.3	64	1.0	98	2.8	243	1.0	177	5.6	283	2.8	288
1.4	78	1.1	124	2.9	269	1.1	215	5.7	334	2.9	346
1.5	93	1.2	153	3.0	295	1.2	255	5.8	392	3.0	408
1.6	110	1.3	184	3.1	320	1.3	297	5.9	456	3.1	482
1.7	130	1.4	216	3.2	348	1.4	341	6.0	525	3.2	593
1.8	152	1.5	250	3.3	372	1.5	385	6.1	599	3.3	781
1.9	176	1.6	283	3.4	397	1.6	429	6.2	677	3.4	968
2.0	201	1.7	316	3.5	423	1.7	473	6.3	759	3.5	1,155
2.1	226	1.8	350	3.6	449	1.8	517	6.4	844	3.6	1,342
2.2	251	1.9	383	3.7	474	1.9	561	6.5	932	3.7	1,529
2.3	276	2.0	416	3.8	500	2.0	605	6.6	1,022	3.8	1,716
2.4	301	2.2	483	3.9	526	.....	.....	6.7	1,114	3.9	1,903
2.5	326	2.4	550	4.0	551	.....	.....	6.8	1,207	4.0	2,090
2.6	352	2.6	616	4.1	577	.....	.....	6.9	1,301	4.1	2,277
2.7	377	2.8	683	.....	.....	.....	.....	7.0	1,396	4.2	2,464
2.8	402	3.0	750	.....	.....	.....	.....	7.1	1,492	4.3	2,651
2.9	427	3.2	816	.....	.....	.....	.....	7.2	1,588	4.4	3,838
3.0	452	3.4	883	.....	.....	.....	.....	7.3	1,684	4.5	3,026
.....	.....	3.6	950	.....	.....	.....	.....	7.4	1,780	4.6	3,214
.....	.....	3.8	1,016	.....	.....	.....	.....	7.5	1,876	.....	.....
.....	.....	4.0	1,083	.....	.....	.....	.....	7.6	1,972	.....	.....
.....	.....	.....	.....	.....	.....	.....	.....	7.7	2,068	.....	.....

a Applicable from April 24 to December 31, 1898.

KANSAS RIVER DRAINAGE.

DESCRIPTION OF RIVER STATIONS.

Superior station on Republican River.—Described on page 107 of Paper No. 16; results for 1897 shown on page 338 of the Nineteenth Annual Report, Part IV. The observer was Carl Schaer. The station was discontinued on December 1, 1898. Flashboards were kept on the dam from September 13 to October 12. As noted in descriptions in Paper No. 16, the gage rod was first placed just above the river highway bridge, which is itself some 75 or 100 yards above the dam which diverts water into the mill race. This gage remained in place during the season of 1898, and was read by the hydrographer in connection with measurements of discharge, the reading being noted under the head of "river gage." At the beginning of the season of 1898 two other gages were installed at this station, one being placed in the river a few feet upstream from the crest of the dam, and the other being placed in the mill race where it is crossed by a wagon bridge about 50 yards below the head of the race. The former of these two additional gages has been called the "dam gage," to distinguish it from the "river gage" previously noted. Its zero was placed as nearly as practicable at the height of the crest of the dam. The gage in the mill race was set so that at the time of setting its reading was 2 feet in excess of that on the "dam gage." The observer was instructed to make daily one set of observations, consisting of the following: Reading on "dam gage," reading of gage in

mill race, and length of time required for float in midstream in mill race to traverse a range of 50 feet which had been staked on the banks.

Measurements of discharge were made, as in previous years, at the highway bridge, thus determining at once the sum of the discharges over the dam and through the mill race. The discharge of the mill race was measured in order that it might be deducted from the total measured discharge of the river to give the amount passing over the dam. It was hoped that the relation between water height on "dam gage" and the amount of water passing over the dam would be stable and regular. It was also hoped that the daily observations of gage height and midstream surface velocity in the mill race would furnish data for the reliable estimation of the amount to be added to that passing over the dam in order to give the total discharge of the river. On computing the results for the season, it appears that while there is not the regularity and degree of certainty hoped for, yet the scheme, with slight modifications, is the best that can be devised for this station. The accompanying table of daily gage heights gives the reading of the gage at the dam, and the computations of discharge for 1898 are based upon the readings at this gage. The height on this gage is also given in the list of discharge measurements rather than that on the river gage.

Junction City station on Republican River.—Described on page 109 of Paper No. 16; results for 1897 given on page 339 of the Nineteenth Annual Report, Part IV.

Niles station on Solomon River.—Described on page 111 of Paper No. 16; results for 1897 given on page 342 of the Nineteenth Annual Report, Part IV.

Salina station on Saline River.—Described on page 113 of Paper No. 16; results for 1897 given on page 343 of the Nineteenth Annual Report, Part IV.

Ellsworth station on Smoky Hill River.—Described on page 114 of Paper No. 16; results for 1897 given on page 346 of the Nineteenth Annual Report, Part IV.

Manhattan station on Blue River.—Described on page 115 of Paper No. 16; results for 1897 given on page 347 of the Nineteenth Annual Report, Part IV.

Lawrence station on Kansas River.—Described on page 116 of Paper No. 16; results for 1897 given on page 349 of the Nineteenth Annual Report, Part IV. The quantity of water passing through the flume leading to the water wheels at this station is very variable. There are eight of these water wheels of several different sizes. They may all be in use at one time, causing a discharge of several hundred second-feet; or only two of them may be running, using a much smaller quantity of water. Even though this flume be carefully rated for any number of these wheels in use, it is difficult to determine which are in use each day and the number of hours they are in use. For these reasons it has been decided to establish a gage at Lecomp-

ton, about 11 miles by rail up the river, where a new carriage bridge across the river will furnish a convenient place for measuring the discharge.

TABLES OF DAILY GAGE HEIGHT.

Daily gage height, in feet, of Republican River at Superior, Nebraska, for 1898 (on gage at dam). (a)

Day.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.
1	.....	0.69	1.21	0.70	0.30	0.09	1.27	0.47
2	.....	1.23	1.06	.73	.34	(b)	1.34	.49
3	.....	.85	1.04	.68	.31	(b)	1.21	.50
4	.....	.86	1.02	.51	.30	2.00	1.21	.54
5	.....	.90	1.04	.61	.30	(b)	1.22	.50
6	.....	1.00	1.19	.61	.30	.59	1.21	.59
7	.....	1.04	1.03	.60	.24	.53	1.24	.53
8	.....	1.14	1.44	.60	.34	.52	1.28	.52
9	.....	1.02	1.26	.72	.26	.53	1.31	.53
10	.....	1.16	1.27	1.24	.24	.09	1.39	.51
11	.....	1.03	1.70	1.04	.21	1.17	1.40	.52
12	.....	.99	1.41	.72	.17	1.35	1.45	.59
13	.....	1.14	1.34	.74	.18	1.42	.43	.64
14	.....	1.22	1.38	.99	.34	1.35	.41	.59
15	.....	.93	1.38	.87	.20	1.34	.40	.60
16	.....	.99	1.36	.74	.21	1.24	.49	.60
17	.....	.96	1.40	.73	.21	1.25	.53	.65
18	.....	.98	1.26	.67	.17	1.35	.43	.63
19	.....	.95	1.47	.61	.18	1.30	.45	.63
20	0.77	1.04	1.29	.55	.05	1.30	.43	.72
21	.77	1.33	1.20	.51	.16	1.65	.42	(c)
22	1.02	1.42	1.11	.60	(b)	1.59	.44	(c)
23	1.63	1.24	1.18	.50	(b)	1.55	.54	(c)
24	1.00	1.00	1.07	.50	.55	1.40	.44	(c)
25	.81	.98	.99	.40	.40	1.47	.43	(c)
26	.76	1.07	.88	.50	.31	1.35	.47	(c)
27	.74	.99	.89	.41	.29	1.32	.39	(c)
28	.74	1.05	.84	.40	.35	1.32	.49	(c)
29	.68	1.50	.80	.40	.28	1.31	.47	(c)
30	.71	1.39	.74	.32	(b)	1.29	.59	(c)
31	.....	1.13	.....	.41	(b)	.....	.49	.....

a Station discontinued December 1. b Water below gage. c Frozen.

Daily gage height, in feet, of mill race on Republican River at Superior, for 1898.

Day.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.
1	.....	2.68	3.20	2.81	2.29	0.92	3.50	2.44
2	.....	3.57	3.07	2.61	2.34	1.53	3.40	2.52
3	.....	2.90	3.21	2.30	2.31	1.49	3.20	2.51
4	.....	2.95	2.95	2.22	2.28	2.70	3.20	2.53
5	.....	2.99	3.10	2.60	2.30	(a)	3.22	2.50
6	.....	3.03	3.24	2.60	2.29	(a)	3.21	2.67
7	.....	3.23	3.12	2.60	2.30	(a)	3.25	2.52
8	.....	3.29	3.09	2.55	2.33	1.60	3.29	2.53
9	.....	3.17	3.42	2.70	2.26	(a)	3.41	2.52
10	.....	3.39	3.58	2.38	2.23	1.95	3.41	2.53
11	.....	3.22	4.11	2.14	2.21	3.18	3.40	2.52
12	.....	3.18	3.64	2.72	2.17	3.38	3.50	2.60
13	.....	3.11	3.40	2.70	2.14	3.43	2.43	2.72
14	.....	3.18	3.50	2.00	2.35	3.35	2.39	2.61
15	.....	3.15	3.59	2.90	2.16	3.34	2.42	2.64
16	.....	3.20	3.57	2.71	2.21	3.25	2.50	2.66
17	.....	3.17	3.60	2.87	2.20	3.25	2.54	2.70
18	.....	3.11	3.35	2.62	2.12	3.40	2.46	2.68
19	.....	3.25	3.70	2.59	2.18	3.30	2.41	2.67
20	2.79	3.18	3.32	2.50	2.05	3.35	2.41	2.81
21	2.79	3.65	3.18	2.49	2.17	3.63	2.40	.....
22	3.37	3.89	3.00	2.45	1.70	4.69	2.40	.....
23	3.06	3.47	3.33	2.40	1.61	3.58	2.60	.....
24	3.17	3.08	3.12	2.50	2.55	3.50	2.41	.....
25	2.79	3.19	3.03	2.38	2.41	3.50	2.40	.....
26	2.69	3.12	2.55	2.51	2.29	3.39	2.43	.....
27	2.67	3.20	2.91	2.07	2.28	3.36	2.10	.....
28	2.65	3.12	2.87	2.38	2.35	3.32	2.50	.....
29	2.69	3.87	2.80	2.40	2.31	3.31	2.44	.....
30	2.70	3.60	2.77	2.31	1.11	3.30	2.60	.....
31	.....	3.29	.....	2.44	1.62	.....	2.49	.....

a Lower than gage board.

Daily gage height, in feet, of Republican River at Junction City, Kansas, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	3.80	3.85	4.00	3.70	5.50	5.20	3.70	2.90	2.40	2.90	2.90	3.30
2	3.85	3.85	3.90	3.80	5.65	5.10	3.70	2.85	2.50	2.80	2.95	3.30
3	3.90	3.90	3.85	3.75	5.30	5.05	3.70	2.85	2.50	2.75	2.95	3.50
4	3.95	4.20	3.85	3.85	4.70	4.70	3.50	2.80	2.50	2.75	3.00	3.45
5	4.10	4.20	3.85	3.85	4.15	4.35	3.60	2.75	2.55	2.75	2.95	3.30
6	4.10	4.15	3.85	3.85	4.55	4.15	3.40	2.70	2.55	2.75	3.00	3.25
7	4.10	4.00	3.85	3.80	4.20	5.35	3.45	2.90	2.55	2.85	3.00	3.35
8	4.10	3.80	3.75	3.85	4.20	6.25	3.55	2.85	2.45	2.70	3.00	3.40
9	4.05	3.80	3.80	4.00	4.20	5.70	3.55	2.75	2.40	2.65	3.00	3.35
10	4.10	4.00	3.85	3.90	4.20	5.85	3.45	2.85	2.60	2.85	3.10	3.40
11	4.10	5.15	3.85	3.90	4.30	5.80	3.40	2.80	2.70	2.80	3.05	3.40
12	4.20	5.10	3.90	3.90	4.35	7.45	3.30	2.80	2.70	2.70	3.10	3.35
13	4.05	4.85	3.85	4.05	4.30	6.75	3.30	2.70	2.75	2.75	3.10	3.25
14	4.10	4.80	3.85	4.10	6.80	6.25	3.30	2.80	2.75	2.85	3.10	3.25
15	4.10	4.75	3.90	3.85	7.90	5.55	3.80	2.65	3.20	2.90	3.20	3.20
16	4.10	4.85	3.85	3.90	6.35	5.35	3.70	2.70	3.20	2.85	3.10	3.30
17	4.00	4.95	3.85	3.95	5.50	5.70	3.50	2.75	3.10	2.90	3.05	3.35
18	3.95	4.75	3.85	4.00	4.90	5.45	3.50	3.00	3.00	2.85	3.20	3.40
19	3.85	4.70	3.95	4.05	5.00	5.20	3.65	2.70	2.80	2.85	3.20	3.40
20	4.05	4.70	4.10	4.15	5.35	5.10	3.50	2.65	2.90	2.85	3.20	3.30
21	4.05	4.35	3.85	4.25	6.95	4.90	3.40	2.60	2.85	2.90	3.20	3.35
22	4.00	4.15	3.70	4.30	6.50	5.65	3.50	2.60	2.85	2.85	3.50	3.80
23	4.00	4.00	3.75	4.30	5.65	5.20	3.30	2.50	2.80	2.85	3.45	3.35
24	3.95	4.00	3.75	4.35	4.95	4.70	3.20	2.50	2.70	2.80	3.35	3.35
25	3.75	3.90	3.65	4.50	4.80	4.35	3.20	2.55	2.60	2.90	3.25	3.35
26	3.75	4.00	3.50	4.30	4.85	4.20	3.10	2.60	2.60	2.95	3.20	3.35
27	3.60	4.00	3.75	4.70	4.80	4.20	3.10	2.50	2.70	3.00	3.25	3.25
28	3.50	4.00	3.80	4.25	4.85	4.10	3.00	2.40	2.75	2.95	3.30	3.35
29	3.55	.....	3.75	4.05	5.00	3.90	3.00	2.45	2.85	2.90	3.35	3.30
30	3.80	.....	3.75	4.20	5.60	3.90	2.90	2.40	2.85	3.00	3.40	3.40
31	3.80	.....	3.65	.....	5.00	.....	2.90	2.50	.....	2.95	.....	3.35

Daily gage height, in feet, of Solomon River at Niles, Kansas, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	5.30	5.40	5.10	5.05	7.25	7.15	5.60	4.60	4.15	4.40	4.15	5.00
2	5.30	5.40	5.35	5.05	5.80	6.40	5.55	4.60	4.10	4.40	4.65	4.95
3	5.30	5.40	5.15	5.00	5.55	6.20	5.50	4.55	4.10	4.45	4.50	4.80
4	5.30	5.40	5.05	5.05	5.60	6.30	5.45	4.50	4.20	4.30	4.55	4.85
5	5.35	5.30	5.05	4.95	5.55	6.05	5.35	4.55	4.10	4.25	4.30	4.80
6	5.40	5.10	5.20	5.00	5.40	5.90	5.25	4.55	4.05	4.40	4.20	4.75
7	5.30	5.10	5.20	5.05	5.45	8.10	5.30	4.50	4.10	4.35	4.45	4.85
8	5.30	5.10	5.10	5.10	5.40	9.40	5.40	4.70	4.05	4.30	4.25	5.05
9	5.30	4.95	5.05	5.10	5.45	8.85	5.70	4.90	4.05	4.25	4.55	5.00
10	5.30	5.15	5.15	4.95	5.50	10.30	5.75	4.60	4.10	4.35	4.55	5.00
11	5.30	5.20	5.20	4.95	5.55	9.10	5.90	4.45	4.05	4.35	4.35	5.00
12	5.40	5.10	5.30	5.00	5.65	8.90	6.15	4.30	4.25	4.30	4.70	5.00
13	5.40	5.40	5.20	5.25	5.75	9.45	6.60	4.30	4.25	4.65	4.30	5.00
14	5.40	5.40	5.30	5.20	6.00	9.30	6.20	4.05	4.15	4.40	4.65	5.00
15	5.40	5.35	5.65	5.15	5.75	8.25	5.75	4.00	4.55	4.40	4.70	5.00
16	5.40	5.60	5.15	5.15	5.55	8.00	5.55	3.95	4.85	4.25	4.60	5.20
17	5.50	5.60	5.05	4.95	6.15	7.60	5.60	3.90	5.35	4.45	4.25	5.20
18	5.50	6.10	5.00	5.10	7.65	7.20	5.45	3.95	4.85	4.25	4.50	5.20
19	5.50	6.15	5.25	5.30	6.15	7.95	5.15	4.05	4.50	4.30	4.70	5.20
20	5.50	6.05	5.35	6.35	5.70	9.25	5.10	4.10	5.40	4.25	4.80	6.10
21	5.50	5.90	5.25	6.70	5.60	8.20	5.10	4.05	5.55	4.40	4.75	6.00
22	5.40	5.65	5.05	5.55	5.60	7.35	5.05	4.10	5.65	4.45	4.45	6.00
23	5.40	5.55	5.15	5.35	5.85	6.95	5.00	4.05	5.30	4.20	4.55	6.20
24	5.40	5.40	5.25	5.15	5.85	6.60	4.95	4.10	4.80	4.20	4.35	6.20
25	5.40	5.35	5.00	5.10	5.70	6.40	4.85	4.15	4.70	4.25	4.35	5.40
26	5.10	5.30	4.90	5.10	6.00	6.20	4.75	4.20	4.65	4.65	4.55	5.50
27	5.10	5.20	5.00	5.05	6.25	6.05	4.75	4.20	4.65	4.40	4.60	5.50
28	5.10	5.25	4.95	4.95	5.90	5.90	4.70	4.15	4.70	4.15	4.70	5.40
29	5.40	.....	4.85	5.90	5.80	5.80	4.70	4.30	4.55	4.15	4.90	5.40
30	5.40	.....	5.10	6.00	7.25	5.70	4.70	4.20	4.50	4.25	5.05	5.40
31	5.40	.....	5.15	.....	8.25	.....	4.65	4.25	.....	4.30	.....	5.30

Daily gage height, in feet, of Saline River at Salina, Kansas, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	3.20	2.90	3.10	2.90	4.35	9.45	3.40	2.65	2.30	3.15	2.60	2.75
2	3.20	3.00	3.05	2.95	4.80	7.15	3.45	2.75	2.20	3.20	3.00	2.80
3	3.20	3.05	2.85	2.90	3.70	5.60	3.50	2.70	2.25	3.15	2.85	2.90
4	3.20	2.90	3.00	2.75	4.00	4.80	3.30	2.70	2.35	3.00	2.80	2.95
5	3.20	2.90	3.05	2.80	3.95	4.45	3.20	2.50	2.55	2.85	2.80	2.80
6	3.20	2.90	2.95	2.95	3.65	4.20	3.30	2.30	2.20	2.85	2.75	2.85
7	3.20	2.85	3.05	2.85	3.35	7.40	3.20	2.80	2.25	3.00	2.80	2.95
8	3.20	2.95	2.95	2.75	3.40	12.60	3.40	2.50	2.30	3.05	2.60	3.05
9	3.25	3.20	2.90	2.80	3.10	8.90	6.40	2.50	2.00	2.90	2.80	3.05
10	3.40	3.40	2.90	2.80	2.90	6.85	7.35	2.70	2.30	3.10	2.75	3.05
11	3.55	3.80	3.00	2.70	3.15	5.40	7.50	2.65	2.30	3.00	2.60	3.05
12	3.65	3.35	3.00	2.80	2.90	4.85	5.20	2.55	2.30	2.75	2.80	2.80
13	3.30	3.70	3.05	3.00	2.90	5.60	3.90	2.60	2.25	2.75	2.85	2.80
14	3.35	3.35	3.00	2.95	2.90	6.65	3.40	2.65	2.45	2.80	2.75	2.80
15	3.45	3.35	2.95	2.75	2.85	5.90	3.25	2.65	2.35	3.05	2.65	2.80
16	3.35	3.40	2.95	2.65	2.90	5.65	3.25	2.65	2.35	2.95	2.65	2.80
17	3.35	3.35	2.85	2.65	3.00	5.05	3.30	2.70	3.80	2.95	2.75	2.80
18	3.25	3.30	2.90	3.00	2.95	4.90	3.25	2.75	3.40	2.85	2.75	2.80
19	3.50	3.20	2.95	2.90	4.75	5.00	3.10	2.45	5.95	2.70	2.75	4.30
20	3.25	3.20	2.95	2.65	3.85	5.80	3.00	2.50	10.65	2.65	2.60	10.15
21	3.35	3.15	2.80	2.80	3.30	4.70	2.90	2.40	10.85	2.60	2.60	7.10
22	3.30	3.10	2.90	2.90	3.25	4.40	2.80	2.35	7.05	2.85	2.40	5.85
23	3.30	3.15	2.95	3.35	3.20	4.40	2.90	2.20	5.10	2.75	2.40	5.75
24	3.55	3.15	2.85	3.15	3.45	4.10	2.95	2.25	4.40	2.80	2.40	5.80
25	3.25	2.95	2.95	3.30	3.60	3.95	2.90	2.60	4.00	2.65	2.40	5.80
26	3.20	2.95	2.85	2.95	3.25	3.90	2.90	2.35	3.85	2.75	2.40	5.20
27	3.30	3.05	2.95	2.75	3.30	3.70	2.65	2.50	3.60	2.70	2.40	5.20
28	3.20	3.10	2.85	2.65	3.45	3.65	2.75	2.75	3.50	2.60	2.40	4.30
29	3.15	.....	2.65	2.85	4.15	3.55	2.85	2.30	3.45	2.80	2.40	4.30
30	3.10	.....	2.65	2.95	4.95	3.50	2.60	2.05	3.40	2.75	2.75	4.30
31	3.00	.....	2.75	.....	11.00	.....	2.60	2.35	.....	2.90	.....	4.10

Daily gage height, in feet, of Smoky Hill River at Ellsworth, Kansas, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	1.28	1.15	1.20	1.00	1.56	2.65	1.50	1.08	.85	1.40	1.00	1.30
2	1.20	1.25	1.18	1.00	1.33	2.35	1.48	1.00	.83	1.38	1.00	1.25
3	1.25	1.25	1.15	1.00	1.23	2.15	1.50	1.00	.83	1.33	1.00	1.25
4	1.30	1.35	1.10	1.00	1.30	1.98	1.43	1.00	.80	1.30	1.00	1.10
5	1.35	1.40	1.10	1.00	1.28	3.00	1.40	.98	.80	1.30	1.00	1.20
6	1.50	1.35	1.10	1.00	1.25	2.30	1.43	.95	.80	1.28	1.00	1.30
7	1.33	1.20	1.10	1.00	1.23	2.25	1.40	1.15	.80	1.25	1.00	1.10
8	1.25	1.25	1.10	1.00	1.20	3.34	1.40	1.00	.80	1.23	1.00	1.25
9	1.18	1.28	1.10	1.00	1.30	2.95	1.38	.98	.80	1.20	1.00	1.15
10	1.20	1.28	1.15	.98	1.30	2.83	1.43	.98	1.00	1.20	1.00	1.10
11	1.23	1.35	1.20	.95	1.30	3.48	1.55	.95	1.35	1.20	1.00	1.10
12	1.23	1.50	1.18	.95	1.30	3.27	1.43	.95	1.35	1.20	1.00	1.10
13	1.23	1.58	1.15	1.00	1.30	2.95	1.38	.98	1.40	1.18	1.00	1.10
14	1.23	1.65	1.13	.95	1.30	2.75	1.33	1.05	1.33	1.15	1.00	1.10
15	1.00	1.55	1.10	.93	1.30	2.65	1.30	1.18	1.50	1.13	1.00	1.10
16	1.03	1.43	1.10	.90	1.30	2.55	1.28	1.13	2.30	1.10	1.00	1.10
17	1.10	1.40	1.08	.85	1.35	2.38	1.25	1.10	3.60	1.10	1.00	1.10
18	.98	1.35	1.10	1.00	1.40	2.25	1.20	1.25	2.45	1.10	1.00	1.10
19	1.23	1.15	1.10	1.03	1.75	2.18	1.20	1.15	2.65	1.10	1.00	1.10
20	1.13	1.15	1.08	1.10	2.05	2.05	1.20	1.10	2.45	1.10	1.00	1.10
21	1.25	1.03	1.05	1.15	1.88	1.98	1.18	1.08	2.65	1.10	1.10	1.90
22	1.25	1.35	.98	1.13	1.75	1.88	1.10	1.03	2.35	1.05	1.10	1.90
23	1.30	1.35	1.05	1.10	1.63	1.80	1.10	1.50	2.15	1.05	1.20	1.90
24	1.25	1.38	1.05	1.08	1.58	1.75	1.10	1.68	1.95	1.05	1.20	1.60
25	1.23	1.28	1.00	1.05	1.53	1.70	1.05	1.03	1.78	1.10	1.10	1.63
26	1.28	1.20	1.00	1.00	1.53	1.68	1.03	.95	1.68	1.10	1.20	1.63
27	1.18	1.20	.93	.98	1.60	1.63	1.00	.93	1.63	1.08	1.20	1.58
28	1.23	1.20	.88	.95	1.85	1.60	1.00	.90	1.58	1.03	1.25	1.50
29	1.20	.....	1.00	.95	4.03	1.55	1.05	.90	1.50	1.00	1.30	1.45
30	1.25	.....	1.00	1.25	3.70	1.53	1.23	.88	1.45	1.00	1.30	1.48
31	1.30	.....	1.00	.....	3.05	.....	1.10	.85	.....	1.00	.....	1.43

Daily gage height, in feet, of Blue River at Manhattan, Kansas, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	4.50	4.05	4.65	4.20	7.95	8.85	5.00	4.00	3.50	3.90	3.65	4.00
2	4.50	4.00	4.60	4.35	7.10	7.90	4.70	4.00	3.45	3.95	3.80	4.10
3	4.60	4.10	4.60	4.30	6.05	7.45	4.35	4.10	3.40	4.00	3.95	4.20
4	4.60	4.20	4.60	4.40	6.45	7.20	4.15	4.05	3.50	3.90	4.05	4.05
5	4.60	4.30	4.50	4.55	6.80	7.20	4.00	4.00	3.60	3.85	3.95	4.00
6	4.50	4.30	4.45	6.00	7.25	6.75	4.20	4.05	3.55	3.75	4.05	3.90
7	4.50	4.40	4.35	5.80	7.40	9.00	4.40	3.90	3.50	3.70	3.95	3.90
8	4.40	4.25	4.25	5.70	7.30	12.00	4.65	3.95	3.60	3.60	3.80	3.85
9	4.40	4.45	4.20	5.40	7.20	13.70	4.95	4.10	3.60	3.55	3.70	4.15
10	4.25	4.60	4.05	5.15	7.00	13.20	5.25	4.00	3.75	3.50	3.70	4.15
11	4.20	9.60	4.10	4.70	6.70	13.00	5.45	3.95	3.85	3.45	3.75	4.10
12	4.20	10.15	4.35	4.60	6.30	13.35	5.35	3.85	3.95	3.40	3.70	4.10
13	4.30	9.85	4.55	4.90	5.95	12.80	5.10	3.80	4.15	3.45	3.80	4.00
14	4.30	9.25	4.70	5.05	7.95	11.50	4.70	3.90	4.30	3.[illegible]	3.90	4.05
15	4.30	8.80	4.75	5.40	7.80	10.75	4.50	3.95	4.25	3.35	3.80	4.15
16	4.45	8.20	4.70	5.45	6.40	10.10	4.40	4.00	4.15	3.40	3.70	4.15
17	4.50	7.55	4.80	5.30	5.85	9.70	4.40	4.00	4.00	3.55	3.75	4.10
18	4.60	7.35	4.90	6.20	5.75	9.40	4.30	4.10	3.85	3.60	3.85	4.05
19	4.60	7.25	4.95	8.15	6.20	9.05	4.25	4.20	3.75	3.75	3.90	4.35
20	4.50	7.15	5.00	7.65	10.30	8.75	4.10	4.10	3.65	3.95	3.80	4.40
21	4.50	7.05	4.75	7.35	12.45	8.40	4.00	4.05	3.60	3.70	3.85	4.45
22	4.60	7.00	4.60	6.40	11.50	8.05	4.00	4.00	3.55	3.75	3.85	4.40
23	4.60	6.70	4.45	5.65	11.65	7.40	4.20	3.95	3.55	3.75	3.85	4.30
24	4.60	6.35	4.30	5.90	10.90	6.90	4.30	3.85	3.75	4.25	3.95	4.45
25	4.50	6.00	4.25	6.75	10.05	6.25	4.20	3.75	3.75	4.15	4.10	4.40
26	4.45	5.70	4.25	6.10	9.70	5.90	4.15	3.65	3.60	3.95	4.00	4.35
27	4.35	5.40	4.15	5.80	9.40	5.55	4.10	3.60	3.55	3.85	4.00	4.45
28	4.25	4.70	4.25	5.60	9.25	5.45	4.00	3.50	3.50	3.70	4.05	4.45
29	4.20	.....	4.30	5.85	9.05	5.20	4.10	3.45	3.65	3.55	4.00	4.50
30	4.15	.....	4.30	6.20	8.55	5.05	4.00	3.40	3.80	3.45	3.95	4.45
31	4.10	.....	4.30	.....	8.10	.....	4.10	3.45	.....	3.45	.....	4.50

Daily gage height, in feet, of Kansas River at Lawrence, Kansas, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	0.10	0.20	0.80	0.60	3.70	3.70	1.50	0.40	—0.40	0.00	0.10	—1.30
2	.20	— .10	.80	.60	4.90	3.60	1.40	.40	— .40	.20	— .05	—1.15
3	.10	— .40	.80	.70	4.00	2.90	1.60	.30	— .40	.00	— .10	+ .10
4	.20	.00	.70	.80	3.10	2.50	1.60	.20	+ .40	— .30	— .05	—2.00
5	.20	.00	.60	1.80	2.50	2.60	1.50	.20	.40	— .80	+ .05	—1.60
6	.20	.40	.60	1.40	2.50	2.10	1.40	.20	.40	—1.10	.15	— .20
7	.20	.60	.60	1.10	2.90	2.00	1.40	.20	.60	—1.20	.10	—1.20
8	.20	.60	.60	1.00	2.60	2.40	1.40	.20	.60	—1.00	.00	— .90
9	.40	.60	.60	1.00	2.10	5.10	1.10	.20	.80	.00	— .15	—2.25
10	.30	.60	.60	1.00	2.00	5.60	1.00	.20	1.00	.00	— .25	—1.45
11	.30	1.00	.60	1.00	1.90	5.20	1.00	.20	1.00	— .80	— .15	— .20
12	.30	1.40	.60	.80	1.70	5.20	.90	.20	1.00	— .90	— .20	— .80
13	.40	1.40	.60	1.00	1.70	4.90	.90	.20	1.00	—1.10	+ .25	—1.60
14	.40	1.40	.60	1.10	3.20	4.70	.90	.20	.90	—1.00	.15	—1.10
15	.40	2.00	.80	1.10	5.25	4.20	.90	.20	.70	—1.00	— .40	—1.10
16	.40	1.80	.70	1.00	5.10	4.40	.80	.20	.20	+ .80	— .25	—1.90
17	.40	1.70	.70	1.10	4.60	3.90	.80	.20	.10	.35	— .10	— .40
18	.40	1.40	.80	1.10	3.90	3.20	.80	.80	.20	.20	— .10	— .50
19	.40	1.40	1.00	1.00	3.40	3.70	.80	.90	.40	.15	.00	— .60
20	.40	1.40	1.20	.90	3.20	3.60	.80	.80	.40	.30	.15	— .60
21	.30	1.20	1.20	1.70	3.35	3.20	.70	.60	.25	.30	— .10	+ .90
22	.30	1.00	1.20	1.90	4.20	2.80	.60	.50	.20	.20	—2.15	1.00
23	.40	1.00	1.20	2.00	4.10	2.50	.60	.30	.05	.35	—1.00	1.00
24	.40	.90	1.10	1.80	4.00	2.30	.60	.20	.00	.25	— .90	1.30
25	.40	.80	.90	1.70	3.70	2.40	.60	.20	.20	— .30	—1.00	1.40
26	.20	.80	.80	1.50	2.90	2.30	.50	.00	.30	—1.40	—1.70	1.20
27	.20	.80	1.60	1.40	3.90	2.20	.40	.00	.35	— .30	+ .10	1.20
28	.40	.80	2.00	1.30	5.10	1.90	.40	.00	.50	— .15	— .90	1.00
29	.40	.....	1.40	1.20	4.70	1.70	.40	— .20	.35	— .10	—1.00	1.05
30	.40	.....	.90	1.80	3.80	1.60	.40	— .40	.10	+ .20	—1.10	1.00
31	.30	.....	.60	.....	3.20	.....	.60	— .40	.....	.30	.....	.70

List of discharge measurements, 1898.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
				Feet.	*Sec.-feet.*
Apr. 20	Mill race, Republican River.	Superior, Nebr.	Glenn E. Smith	2.79	87
May 10	do	do	do	3.39	65
May 27	do	do	do	3.12	50
June 17	do	do	do	3.60	52
June 27	do	do	do	2.91	52
July 19	do	do	do	2.50	85
Aug. 6	do	do	do	2.29	56
Aug. 28	do	do	do	2.35	11
Sept. 13	do	do	do	3.40	68
Oct. 9	do	do	do	3.40	8
Nov. 5	do	do	do	2.50	86
Apr. 20	Republican River	do	do	.79	626
May 10	do	do	do	1.16	1,337
May 27	do	do	do	1.05	1,080
June 17	do	do	do	1.40	1,573
June 27	do	do	O. V. P. Stout	.89	679
July 19	do	do	Glenn E. Smith	.60	416
Aug. 6	do	do	do	.30	119
Aug. 28	do	do	Adna Dobson	.15	76
Sept. 13	do	do	Glenn E. Smith	1.40	252
Oct. 9	do	do	Adna Dobson	1.18	143
Nov. 5	do	do	Glenn E. Smith	.50	380
Feb. 16	do	Junction City, Kans.	W. G. Russell	4.80	1,409
Mar. 2	do	do	do	3.90	686
Apr. 27	do	do	do	4.90	1,327
May 6	do	do	do	4.50	1,226
May 23	do	do	do	5.35	2,179
July 28	do	do	do	3.00	355
Sept. 13	do	do	do	2.70	.189
Oct. 18	do	do	do	2.80	159
Feb. 17	Solomon River	Niles, Kans.	do	5.70	227
Mar. 2	do	do	do	5.40	157
Apr. 27	do	do	do	5.10	116
May 7	do	do	do	5.50	156
May 24	do	do	do	6.00	235
July 29	do	do	do	4.70	94
Sept. 14	do	do	do	4.20	50
Oct. 20	do	do	do	4.30	49
Feb. 17	Saline River	Salina, Kans.	do	3.30	50
Mar. 3	do	do	do	2.80	32
Apr. 28	do	do	do	2.70	39
May 7	do	do	do	3.20	71
May 24	do	do	do	3.50	76
July 29	do	do	do	2.70	33
Sept. 14	do	do	do	2.20	14
Sept. 19	do	do	do	6.80	a 355
Do	do	do	do	8.15	b 512
Sept. 20	do	do	do	10.45	c 718
Oct. 21	do	do	do	2.60	20
Feb. 4	Smoky Hill River	Ellsworth, Kans.	do	1.30	26
Apr. 25	do	do	do	1.05	28
May 4	do	do	do	1.30	42
May 21	do	do	do	1.85	134
May 29	do	do	do	4.20	1,083
June 25	do	do	do	1.80	142
July 29	do	do	do	1.10	29
Aug. 24	do	do	do	1.40	39
Sept. 15	do	do	do	1.50	75
Sept. 16	do	do	do	2.15	208
Oct. 24	do	do	do	1.05	16
Apr. 18	Blue River	Manhattan, Kans.	O. P. Hood	5.00	1,056
Apr. 25	do	do	do	7.00	2,419
May 23	do	do	do	13.70	10,780
Oct. 19	do	do	do	3.80	423
Feb. 22	Kansas River	Lawrence, Kans.	E. C. Murphy	1.08	3,226
July 8	do	do	do	1.43	4,529
Nov. 19	do	Lecompton, Kans. d	do	−.32	954

a 2 p. m.
b 6 p. m.
c 7 a. m.
d Miscellaneous measurements.

Rating tables.

Junction City.		Niles.		Salina.		Ellsworth.		Manhattan.		Lawrence.	
Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*
2.0	28	4.0	40	2.0	6	0.8	14	3.0	50	—1.9	542
2.2	44	4.2	50	2.2	10	.9	16	3.2	140	—1.8	552
2.4	69	4.4	62	2.4	15	1.0	18	3.4	230	—1.6	572
2.6	110	4.6	75	2.6	22	1.1	24	3.6	320	—1.4	592
2.8	175	4.8	92	2.8	32	1.2	32	3.8	410	—1.2	612
3.0	252	5.0	115	3.0	40	1.3	42	4.0	500	—1.0	632
3.2	325	5.2	137	3.2	52	1.4	55	4.5	775	— .8	652
3.4	425	5.4	160	3.4	63	1.5	70	5.0	1,060	— .6	672
3.6	530	5.6	184	3.6	79	1.6	86	5.5	1,365	— .4	692
3.8	645	5.8	209	3.8	94	1.7	105	6.0	1,680	— .2	712
4.0	760	6.0	238	4.0	109	1.8	126	6.5	2,050	.0	787
4.2	900	6.2	268	4.2	125	1.9	147	7.0	2,420	.2	967
4.4	1,055	6.4	299	4.4	139	2.0	170	7.5	2,810	.4	1,255
4.6	1,220	6.6	335	4.6	157	2.1	196	8.0	3,200	.6	1,643
4.8	1,420	6.8	371	4.8	175	2.2	225	8.5	3,650	.8	2,123
5.0	1,675	7.0	406	5.0	193	2.3	253	9.0	4,100	1.0	2,687
5.2	1,970	7.2	441	5.2	209	2.4	283	9.5	4,615	1.5	4,412
5.4	2,250	7.4	480	5.4	225	2.5	312	10.0	5,130	2.0	6,490
5.6	2,560	7.6	522	5.6	243	2.6	343	10.5	5,760	2.5	8,840
5.8	2,900	7.8	570	5.8	261	2.7	376	11.0	6,390	3.0	11,440
6.0	3,245	8.0	619	6.0	279	2.8	410	11.5	7,060	3.5	14,290
6.2	3,610	8.2	664	6.5	324	2.9	450	12.0	7,770	4.0	17,390
6.4	3,975	8.4	718	7.0	373	3.0	490	12.5	8,635	4.5	20,740
6.6	4,350	8.6	760	7.5	421	3.2	573	13.0	9,500	5.0	24,340
6.8	4,780	8.8	808	8.0	470	3.4	670	13.5	10,410	5.5	28,190
7.0	5,200	9.0	854	8.5	519	3.6	763	14.0	11,320	6.0	32,290
7.2	5,610	9.5	973	9.0	569	3.8	867	14.5	12,215	6.5	36,640
7.4	6,050	10.0	1,100	9.5	620	4.0	975	15.0	13,110	7.0	41,230
				10.0	673			15.5	14,005		
				10.5	732			16.0	14,900		

CONVERSION TABLES.

The following tables for converting common units employed in water measurement have been inserted for the purpose of facilitating computations. At the head of each table is placed the factor used, this in the case of decimals being carried out usually to seven places.

Cubic feet into gallons.

1 cubic foot = 1,728 cubic inches = $\frac{1,728}{231}$ gallons = 7.4805194 gallons.

[In gallons.]

1 cubic foot	7.4805194	6 cubic feet	44.8831164
2 cubic feet	14.9610388	7 cubic feet	52.3636358
3 cubic feet	22.4415582	8 cubic feet	59.8441552
4 cubic feet	29.9220776	9 cubic feet	67.3246746
5 cubic feet	37.4025970		

	0.	1.	2.	3.	4.	5.	6.	7.	8.	9.
0	-------	7.48	14.96	22.44	29.92	37.40	44.88	52.36	59.84	67.32
10	74.81	82.28	89.77	97.25	104.73	112.21	119.69	127.17	134.65	142.13
20	149.61	157.09	164.57	172.05	179.53	187.01	194.49	201.97	209.45	216.94
30	224.42	231.90	239.38	246.86	254.34	261.82	269.30	276.78	284.26	291.74
40	299.22	306.70	314.18	321.66	329.14	336.62	344.10	351.58	359.06	366.55
50	374.03	381.51	388.99	396.47	403.95	411.43	418.91	426.39	433.87	441.35
60	448.83	456.31	463.79	471.27	478.75	486.23	493.71	501.19	508.68	516.16
70	523.64	531.12	538.60	546.08	553.56	561.04	568.52	576.00	583.48	590.96
80	598.44	605.92	613.40	620.88	628.36	635.84	643.32	650.81	658.29	665.77
90	673.25	680.73	688.21	695.69	703.17	710.65	718.13	725.61	733.09	740.57

Gallons into cubic feet.

1 United States liquid gallon = 231 cubic inches = $\frac{231}{1,728}$ cubic foot = 0.13368055 cubic feet.

[In cubic feet.]

1 gallon	0.13368055	6 gallons	0.80208330
2 gallons	.26736110	7 gallons	.93576385
3 gallons	.40104165	8 gallons	1.06944440
4 gallons	.53472220	9 gallons	1.20312495
5 gallons	.66840275		

	0.	1.	2.	3.	4.	5.	6.	7.	8.	9.
0	.....	0.1337	0.2674	0.4010	0.5347	0.6684	0.8021	0.9358	1.0694	1.2031
10	1.3368	1.4705	1.6042	1.7378	1.8715	2.0052	2.1389	2.2726	2.4062	2.5399
20	2.6736	2.8073	2.9410	3.0746	3.2083	3.3420	3.4757	3.6094	3.7430	3.8767
30	4.0104	4.1441	4.2778	4.4114	4.5451	4.6788	4.8125	4.9462	5.0798	5.2135
40	5.3472	5.4809	5.6146	5.7482	5.8819	6.0156	6.1493	6.2830	6.4166	6.5503
50	6.6840	6.8177	6.9514	7.0850	7.2187	7.3524	7.4861	7.6198	7.7534	7.8871
60	8.0208	8.1545	8.2882	8.4218	8.5555	8.6892	8.8229	8.9566	9.0902	9.2239
70	9.3576	9.4913	9.6250	9.7586	9.8923	10.0260	10.1597	10.2934	10.4270	10.5607
80	10.6944	10.8281	10.9618	11.0954	11.2291	11.3628	11.4965	11.6302	11.7638	11.8975
90	12.0312	12.1649	12.2986	12.4322	12.5659	12.6996	12.8333	12.9670	13.1006	13.2343

Feet per second into miles per hour.

1 foot per second = 3,600 feet per hour = $\frac{3,600}{5,280}$ or $\frac{15}{22}$ miles per hour.

[In miles per hour.]

1 foot per second	0.68182	6 feet per second	4.09091
2 feet per second	1.36364	7 feet per second	4.77273
3 feet per second	2.04545	8 feet per second	5.45455
4 feet per second	2.72727	9 feet per second	6.13636
5 feet per second	3.40909		

(See Smithsonian Meteorological Tables, No. 52.)

	0.	1.	2.	3.	4.	5.	6.	7.	8.	9.
0	.....	0.6818	1.3636	2.0455	2.7273	3.4091	4.0909	4.7727	5.4546	6.1364
10	6.8182	7.5000	8.1818	8.8637	9.5455	10.2273	10.9091	11.5909	12.2728	12.9546
20	13.6336	14.3182	15.0000	15.6819	16.3637	17.0455	17.7273	18.4091	19.0910	19.7728
30	20.4546	21.1364	21.8182	22.5001	23.1819	23.8637	24.5455	25.2273	25.9092	26.5910
40	27.2728	27.9546	28.6364	29.3183	30.0001	30.6819	31.3637	32.0455	32.7274	33.4092
50	34.0910	34.7728	35.4546	36.1365	36.8183	37.5001	38.1819	38.8637	39.5456	40.2274
60	40.9092	41.5910	42.2728	42.9547	43.6365	44.3183	45.0001	45.6819	46.3638	47.0456
70	47.7274	48.4092	49.0910	49.7729	50.4547	51.1365	51.8183	52.5001	53.1820	53.8638
80	54.5456	55.2274	55.9092	56.5911	57.2729	57.9547	58.6365	59.3183	60.0002	60.6820
90	61.3638	62.0456	62.7274	63.4093	64.0911	64.7729	65.4547	66.1365	66.8184	67.5002

Miles per hour into feet per second.

1 mile per hour = 5,280 feet per hour = $\frac{5,280}{3,600}$ or $\frac{22}{15}$ feet per second.

[In feet per second.]

1 mile per hour	1.46667	6 miles per hour	8.80000
2 miles per hour	2.93333	7 miles per hour	10.26667
3 miles per hour	4.40000	8 miles per hour	11.73333
4 miles per hour	5.86667	9 miles per hour	13.20000
5 miles per hour	7.33333		

(See Smithsonian Meteorological Tables, No. 51.)

	0.	1.	2.	3.	4.	5.	6.	7.	8.	9.
0	.....	1.4667	2.9333	4.4000	5.8667	7.3333	8.8000	10.2667	11.7333	13.2000
10	14.6667	16.1333	17.6000	19.0667	20.5333	22.0000	23.4667	24.9333	26.4000	27.8667
20	29.3333	30.8000	32.2667	33.7333	35.2000	36.6667	38.1333	39.6000	41.0667	42.5333
30	44.0000	45.4667	46.9333	48.4000	49.8667	51.3333	52.8000	54.2667	55.7333	57.2000
40	58.6667	60.1333	61.6000	63.0667	64.5333	66.0000	67.4667	68.9333	70.4000	71.8667
50	73.3333	74.8000	76.2667	77.7333	79.2000	80.6667	82.1333	83.6000	85.0667	86.5333
60	88.0000	89.4667	90.9333	92.4000	93.8667	95.3333	96.8000	98.2667	99.7333	101.2000
70	102.6667	104.1333	105.6000	107.0667	108.5333	110.0000	111.4667	112.9333	114.4000	115.8667
80	117.3333	118.8000	120.2667	121.7333	123.2000	124.6667	126.1333	127.6000	129.0667	130.5333
90	132.0000	133.4667	134.9333	136.4000	137.8667	139.3333	140.8000	142.2667	143.7333	145.2000

Second-feet per day into millions of gallons.

1 second-foot, or 7.4805194 gallons per second for 1 day, or 86,400 seconds = 646,316.87616 gallons.

[In gallons.]

1 second-foot for 24 hours	646,316.87616	6 second-feet for 24 hours	3,877,901.26
2 second-feet for 24 hours	1,292,633.75	7 second-feet for 24 hours	4,524,218.13
3 second-feet for 24 hours	1,938,950.63	8 second-feet for 24 hours	5,170,535.01
4 second-feet for 24 hours	2,585,267.50	9 second-feet for 24 hours	5,816,851.88
5 second-feet for 24 hours	3,231,584.38		

	0.	1.	2.	3.	4.	5.	6.	7.	8.	9.
0	.....	0.6463	1.2926	1.9390	2.5853	3.2316	3.8779	4.5242	5.1705	5.8169
10	6.4632	7.1095	7.7558	8.4022	9.0484	9.6947	10.3411	10.9874	11.6337	12.2800
20	12.9263	13.5727	14.2190	14.8653	15.5116	16.1579	16.8042	17.4505	18.0969	18.7432
30	19.3895	20.0358	20.6821	21.3285	21.9748	22.6211	23.2674	23.9137	24.5600	25.2064
40	25.8527	26.4991	27.1454	27.7918	28.4380	29.0843	29.7307	30,3770	31.0233	31.6706
50	32.3158	32.9622	33.6085	34.2548	34.9011	35.5474	36.1937	36.8401	37.4864	38.1327
60	38.7790	39.4253	40.0716	40.7180	41.3643	42.0106	42.6576	43.3032	43.9495	44.5959
70	45.2422	45.8885	46.5348	47.1812	47.8275	48.4768	49.1201	49.7664	50.4127	51.0590
80	51.7053	52.3517	52.9980	53.6444	54.2906	54.9339	55.5833	56.2296	56.8759	57.5222
90	58.1685	58.8149	59.4612	60.1075	60.7538	61.4001	62.0464	62.6927	63.3391	63.9854

Millions of gallons into second-feet per day.

1 million gallons per 24 hours = $\frac{231,000,000}{1728\times86400}$ cubic feet per second, or 1.5472286 second-feet.

[In second-feet per 24 hours.]

1 million gallons	1.5472286	6 million gallons	9.2833716
2 million gallons	3.0944572	7 million gallons	10.8306002
3 million gallons	4.6416858	8 million gallons	12.3778288
4 million gallons	6.1889144	9 million gallons	13.9250574
5 million gallons	7.7361430		

	0.	1.	2.	3.	4.	5.	6.	7.	8.	9.
0	.....	1.5472	3.0945	4.6417	6.1889	7.7361	9.2834	10.8306	12.3778	13.9251
10	15.4723	17.0195	18.5667	20.1140	21.6612	23.2084	24.7556	26.3029	27.8501	29.3973
20	30.9446	32.4918	34.0390	35.5862	37.1335	38.6807	40.2279	41.7752	43.3224	44.8696
30	46.4169	47.9641	49.5113	51.0585	52.6058	54.1530	55.7002	57.2474	58.7947	60.3419
40	61.8891	63.4364	64.9836	66.5308	68.0781	69.6253	71.1725	72.7197	74.2669	75.8142
50	77.3614	78.9087	80.4559	82.0031	83.5503	85.0976	86.6448	88.1920	89.7393	91.2865
60	92.8337	94.3809	95.9282	97.4754	99.0226	100.5699	102.1171	103.6643	105.2115	106.7588
70	108.3060	109.8532	111.4005	112.9487	114.4949	116.0421	117.5894	119.1366	120.6838	122.2311
80	123.7783	125.3255	126.8727	128.4200	129.9672	131.5144	133.0617	134.6089	136.1561	137.7033
90	139.2506	140.7978	142.3450	143.8923	145.4395	146.9867	148.5339	150.0812	151.6284	153.1756

Second-feet per day into acre-feet.

1 second-foot flow for 1 day = 86,400 cubic feet = $\frac{86,400}{43,560}$ or 1.983471 acre-feet.

[In acre-feet.]

1 second-foot for 24 hours	1.98347	6 second feet for 24 hours	11.90082
2 second-feet for 24 hours	3.96694	7 second-feet for 24 hours	13.88429
3 second-feet for 24 hours	5.95041	8 second-feet for 24 hours	15.86776
4 second-feet for 24 hours	7.93388	9 second-feet for 24 hours	17.85123
5 second-feet for 24 hours	9.91735		

	0.	1.	2.	3.	4.	5.	6.	7.	8.	9.
0	.....	1.983	3.967	5.950	7.934	9.917	11.901	13.884	15.868	17.851
10	19.835	21.818	23.802	25.785	27.769	29.752	31.736	33.719	35.702	37.686
20	39.669	41.653	43.636	45.620	47.603	49.587	51.570	53.554	55.537	57.521
30	59.504	61.488	63.471	65.455	67.438	69.421	71.405	73.388	75.372	77.355
40	79.339	81.322	83.306	85.289	87.273	89.256	91.240	93.223	95.207	97.190
50	99.174	101.157	103.140	105.124	107.107	109.091	111.074	113.058	115.041	117.025
60	119.008	120.992	122.975	124.959	126.942	128.926	130.909	132.892	134.876	136.859
70	138.843	140.826	142.810	144.793	146.777	148.760	150.744	152.728	154.711	156.694
80	158.678	160.661	162.645	164.628	166.611	168.595	170.578	172.562	174.545	176.529
90	178.512	180.496	182.479	184.463	186.446	188.430	190.413	192.397	194.380	196.364

Acre-feet into second-feet flow for 24 hours.

One acre-foot each 24 hours = 43,560 cubic feet each 86,400 seconds = $\frac{43,560}{86,400}$, or $\frac{121}{240}$ second-foot flow for 24 hours.

[In second-feet for 24 hours.]

1 acre-foot	.50417	6 acre-feet	3.02500
2 acre-feet	1.00833	7 acre-feet	3.52917
3 acre-feet	1.51250	8 acre-feet	4.03334
4 acre-feet	2.01667	9 acre-feet	4.53750
5 acre-feet	2.52084		

	0.	1.	2.	3.	4.	5.	6.	7.	8.	9.
0	.....	.504	1.008	1.513	2.017	2.521	3.025	3.529	4.033	4.538
10	5.042	5.546	6.050	6.554	7.058	7.563	8.067	8.571	9.075	9.579
20	10.083	10.588	11.092	11.596	12.100	12.604	13.108	13.613	14.117	14.621
30	15.125	15.629	16.133	16.638	17.142	17.646	18.150	18.654	19.158	19.663
40	20.167	20.671	21.175	21.679	22.188	22.688	23.192	23.696	24.200	24.704
50	25.209	25.713	26.217	26.721	27.225	27.729	28.234	28.738	29.242	29.746
60	30.250	30.754	31.259	31.763	32.267	32.771	33.275	33.779	34.284	34.788
70	35.292	35.796	36.300	36.804	37.309	37.813	38.317	38.821	39.325	39.829
80	40.334	40.838	41.342	41.846	42.350	42.854	43.359	43.863	44.367	44.871
90	45.375	45.880	46.384	46.888	47.392	47.896	48.400	48.905	49.409	49.913

Acre-feet into millions of gallons.

1 acre-foot = 43,560 cubic feet = $\frac{43,560 \times 1,728}{231}$ or $\frac{75,271,680}{231}$, or 325,851.428 gallons.

[In gallons.]

	Millions.	Thousands.		Millions.	Thousands.
1 acre-foot	0.325851428	325.9	6 acre-feet	1.95510858	1,955.1
2 acre-feet	.65170286	651.7	7 acre-feet	2.28096001	2,281.0
3 acre-feet	.97755429	977.6	8 acre-feet	2.60681144	2,606.8
4 acre-feet	1.30340572	1,303.4	9 acre-feet	2.93266287	2,932.7
5 acre-feet	1.62925715	1,629.3			

	0.	1.	2.	3.	4.	5.	6.	7.	8.	9.
0	.....	0.3259	0.6517	0.9776	1.3034	1.6293	1.9551	2.2810	2.6068	2.9327
10	3.2585	3.5844	3.9102	4.2361	4.5619	4.8878	5.2136	5.5395	5.8653	6.1912
20	6.5170	5.8429	7.1687	7.4946	7.8204	8.1463	8.4721	8.7980	9.1238	9.4497
30	9.7755	10.1014	10.4272	10.7531	11.0789	11.4048	11.7306	12.0565	12.3823	12.7082
40	13.0341	13.3599	13.6857	14.0116	14.3374	14.6633	14.9891	15.3150	15.6408	15.9667
50	16.2926	16.6184	16.9443	17.2701	17.5960	17.9218	18.2477	18.5735	18.8994	19.2252
60	19.5511	19.8769	20.2028	20.5286	20.8545	21.1803	21.5062	21.8320	22.1579	22.4837
70	22.8096	23.1354	23.4613	23.7871	24.1130	24.4388	24.7647	25.0905	25.4164	25.7422
80	26.0681	26.3939	26.7198	27.0456	27.3715	27.6973	28.0232	28.3490	28.6749	29.0007
90	29.3266	29.6524	29.9783	30.3041	30.6300	30.9558	31.2817	32.6075	31.9334	32.2592

Millions of gallons into acre-feet.

One million United States liquid gallons or 231 million cubic inches = 133,680.555 cubic feet, or

$$\frac{133,680}{43,560} = 3.0688832 \text{ acre-feet.}$$

[In acre-feet.]

1 million gallons	3.0688832	6 million gallons	18.4132993
2 million gallons	6.1377664	7 million gallons	21.4821826
3 million gallons	9.2066496	8 million gallons	24.5510659
4 million gallons	12.2755328	9 million gallons	27.6199492
5 million gallons	15.3444160		

	0.	1.	2.	3.	4.	5.	6.	7.	8.	9.
0	.....	3.069	6.138	9.207	12.276	15.344	18.413	21.482	24.551	27.620
10	30.689	33.758	36.827	39.895	42.964	46.033	49.102	52.171	55.240	58.309
20	61.378	64.446	67.515	70.584	73.653	76.722	79.791	82.860	85.929	88.998
30	92.066	95.135	98.204	101.273	104.342	107.411	110.480	113.549	116.618	119.686
40	122.755	125.824	128.893	131.962	135.031	138.100	141.169	144.238	147.306	150.375
50	153.444	156.513	159.582	162.651	165.720	168.789	171.857	174.926	177.995	181.064
60	184.133	187.202	190.271	193.340	196.409	199.477	202.546	205.615	208.684	211.753
70	214.822	217.891	220.960	224.028	227.097	230.166	233.235	236.304	239.373	242.442
80	245.511	248.580	251.648	254.717	257.786	260.855	263.924	266.993	270.062	273.131
90	276.199	279.268	282.337	285.406	288.475	291.544	294.613	297.682	300.751	303.819

Second-feet into minute-gallons.

Factors: 1 cubic foot contains 1,728 cubic inches; 1 gallon has a capacity of 231 cubic inches; 1 second-foot equals [(1,728 ÷ 231) × 60] gallons per minute, or 448.831164 minute-gallons.

[In gallons per minute.]

1 second-foot	448.831164	6 second-feet	2,692.986984
2 second-feet	897.662328	7 second-feet	3,141.818148
3 second-feet	1,346.493492	8 second-feet	3,590.649312
4 second-feet	1,795.324656	9 second-feet	4,039.480476
5 second-feet	2,244.155820		

	0.	1.	2.	3.	4.	5.	6.	7.	8.	9.
0	.....	449	898	1,346	1,795	2,244	2,693	3,142	3,591	4,039
10	4,488	4,937	5,386	5,835	6,284	6,732	7,181	7,630	8,079	8,528
20	8,977	9,425	9,874	10,323	10,772	11,221	11,670	12,118	12,567	13,016
30	13,465	13,914	14,363	14,811	15,260	15,709	16,158	16,607	17,056	17,504
40	17,953	18,402	18,851	19,300	19,749	20,197	20,646	21,095	21,544	21,993
50	22,442	22,890	23,339	23,788	24,237	24,686	25,135	25,583	26,032	26,481
60	26,930	27,379	27,828	28,276	28,725	29,174	29,623	30,072	30,521	30,969
70	31,418	31,867	32,316	32,765	33,214	33,662	34,111	34,560	35,009	35,458
80	35,906	36,355	36,804	37,253	37,702	38,151	38,599	39,048	39,497	39,946
90	40,395	40,844	41,292	41,741	42,190	42,639	43,088	43,537	43,985	44,434

Minute-gallons into second-feet.

Factors: 1 gallon contains 231 cubic inches; 1 cubic foot contains 1,728 cubic inches; 1 gallon per minute equals [(231÷1,728)÷60] second-feet, or .002,228,009, 2 second-feet.

[In second-feet.]

1 minute-gallon	0.002,228,009	6 minute-gallons	0.013,368,055
2 minute-gallons	.004,456,018	7 minute-gallons	.015,596,064
3 minute-gallons	.006,684,028	8 minute-gallons	.017,824,074
4 minute-gallons	.008,912,037	9 minute-gallons	.020,052,083
5 minute-gallons	.011,140,046		

	0.	1.	2.	3.	4.	5.	6.	7.	8.	9.
0	.....	0.0022	0.0045	0.0067	0.0089	0.0111	0.0134	0.0156	0.0178	0.0201
10	0.0223	.0245	.0267	.0290	.0312	.0334	.0356	.0379	.0401	.0423
20	.0446	.0468	.0490	.0512	.0535	.0557	.0579	.0602	.0624	.0646
30	.0668	.0691	.0713	.0735	.0758	.0780	.0802	.0824	.0847	.0869
40	.0891	.0913	.0936	.0958	.0980	1.0026	1.0249	1.0472	1.0694	1.0917
50	1.1140	1.1363	1.1586	1.1808	1.2031	1.2254	1.2477	1.2700	1.2922	1.3145
60	1.3368	1.3591	1.3814	1.4036	1.4259	1.4482	1.4705	1.4928	1.5150	1.5373
70	1.5596	1.5819	1.6042	1.6264	1.6487	1.6710	1.6933	1.7156	1.7378	1.7601
80	1.7824	1.8047	1.8270	1.8492	1.8715	1.8938	1.9161	1.9384	1.9606	1.9829
90	2.0052	2.0275	2.0498	2.0720	2.0943	2.1166	2.1389	2.1612	2.1834	2.2057

[For index, see Part II of this report—Water-Supply Paper No. 28.]

55TH CONGRESS, 3d Session. } HOUSE OF REPRESENTATIVES. { DOCUMENT No. 298.

DEPARTMENT OF THE INTERIOR

WATER-SUPPLY

AND

IRRIGATION PAPERS

OF THE

UNITED STATES GEOLOGICAL SURVEY

No. 28

OPERATIONS AT RIVER STATIONS, 1898.—PART II

WASHINGTON
GOVERNMENT PRINTING OFFICE
1899

UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

OPERATIONS AT RIVER STATIONS, 1898

A REPORT OF THE

DIVISION OF HYDROGRAPHY

OF THE

UNITED STATES GEOLOGICAL SURVEY

PART II

WASHINGTON
GOVERNMENT PRINTING OFFICE
1899

CONTENTS.

	Page.
Letter of transmittal	106
Arkansas River drainage	107
Western Gulf drainage	118
Colorado River drainage	131
Interior basin drainage	145
Columbia River drainage	155
Northern Pacific coast drainage	171
San Francisco Bay drainage	177
Southern California drainage	186
Index	197

flow. The cross section of the channel is good, but fills up somewhat in low water and scours in high water. The observer is Mr. C. W. Reece, water commissioner of district No. 14. Readings are also taken at this point by the Pueblo city engineer.

Nepesta station on Arkansas River.—Described on page 121 of Paper No. 16; results for 1897 given on page 358 of the Nineteenth Annual Report, Part IV. S. M. Butts was observer until July 2, and J. P. Haines for balance of the year.

Rocky Ford station on Arkansas River.—Described on page 122 of Paper No. 16.

Manzanola station on Arkansas River.—This station is located about one-half of a mile north of Manzanola, Colorado, at a wagon bridge, and was first established September 29, 1897, by Porter J. Preston, when a measurement was made, showing a discharge of 208 second-feet. The rod was changed in May, 1898, however, and is now nailed to a 2 by 4 inch timber, which is securely fastened to an iron pier in the center of the stream. The rod consists of a 2 by 6 inch by 12-foot timber, marked in tenths by means of a 1 by 6 inch scale. The initial point for soundings is on the right bank, which is high, while the left is low and liable to overflow. The river bends at this point and is not straight for any considerable distance above or below, but the channel, which is in sand and gravel, is not liable to much change. The observer was M. D. Lyle, a ditch rider on the Catlin Canal. No sufficient number of discharge measurements were made upon which to base a rating table.

Trinidad station on Purgatory River.—Described on page 123 of Paper No. 16; results for 1897 given on pages 358–360 of the Nineteenth Annual Report, Part IV.

J. J. Ranch station on Purgatory River.—This station is located 22 miles south of Lajunta, Colorado, and is approximately 27 miles above the mouth of the Purgatory River. The gage rod is placed one-half mile below the mouth of Smith Canyon, a large tributary of the Purgatory. It is nailed to a pole, which is securely fastened by means of stakes driven into the bank. The rod was originally graduated for a vertical position, but was afterwards placed in a sloping position. The elevations of the several footmarks were taken with a wye level, and a correction table was made, giving the corresponding vertical values for the inclined rod. The elevation of the gage rod was established in reference to a bench mark placed on the foot of a large cottonwood tree. The river channel is straight for a distance of 400 feet above and 250 feet below the gage rod. The bottom is of gravel, and there is considerable fall both above and below the rod. The discharge measurements were taken in 1898 by C. W. Beach, but owing to the fact that the two gagings were made at times when the gage rod was in different positions, there is no known relationship between them, and no rating table was constructed. The observer is Edward Sanborn, a ranch laborer.

Las Animas station on Arkansas River.—This station is located about one-half of a mile north of Las Animas, Colorado, at a wagon bridge, having been established May 13, 1898. The gage consists of a 1 by 5 inch board marked in tenths and wired securely to an iron bridge pier on south side of river and upstream side of bridge. The river is straight for 200 feet above and 300 feet below; the bed is sandy and shifting. The banks are not liable to overflow excepting at very high water. The observer was C. W. Beach in May and C. L. Morris after July 19. No gagings were made in 1898.

Amity Canal headgates on the Arkansas River.—This station is located at the head of the Amity Canal, 7 miles west of Lamar, Colorado. The canal is taken out on the north side of the river at a point where there is a wooden dam extending across the stream. The dam is 365 feet long; the crest of the last 81 feet on the south side is 15 inches higher than the crest of the remaining 284 feet, which latter is 4 feet and 4 inches above the floor of the head gates. The river at this point washes against a sandstone bluff. The dam makes the river channel unchangeable, and, taken in connection with the canal, it furnishes an excellent place for obtaining the total discharge of the Arkansas River at this point. During the past year the gagings of the canal have been taken in its rating flume; this necessitates a separate gage for crest of dam. It is expected, however, that on January 1, 1899, one gage rod will be so placed as to serve both for the dam and the canal. The observer is Mr. E. R. Bannister, headgate keeper of the Amity Canal.

Granada station on Arkansas River.—This station was located at the head gate of the Buffalo Creek Canal, 2 miles northeast of Granada. The equipment consists of a bridge upon the head gate of the canal, there being an earth dam across the Arkansas at this point, which sometimes breaks during high water and has to be repaired, thus making the results of the gage readings of not great value, excepting as showing the rise and fall of the water. The gage rod is vertical and well painted, nailed to the head gate. The channel is straight for about 2,600 feet above and about 800 feet below, and the water runs swiftly both above and below. The banks are high on each side and the bed of the stream is of gravel and more or less changeable. The observer is Ben Riley, a ditch rider of the Buffalo Creek ditch, who takes the observations once each day at 7 a. m. No gagings have been made at this point, as the bed of the stream is so changeable that gagings would be of but little value. It is expected that different arrangements, giving more valuable results, can be made during 1899.

Hutchinson station on Arkansas River.—Described on page 124 of Paper No. 16; results for 1897 given on pages 360–361 of the Nineteenth Annual Report, Part IV.

Liberty station on Verdigris River.—Described on page 125 of Paper No. 16; results for 1897 given on pages 369–372 of the Nineteenth Annual Report, Part IV.

Iola station on Neosho River.—Described on page 126 of Paper No. 16; results for 1897 given on pages 361–363 of the Nineteenth Annual Report, Part IV.

TABLES OF DAILY GAGE HEIGHT.

Daily gage height, in feet, of Arkansas River at Granite, Colorado, for 1898.

Day.	Aug.	Sept.	Day.	Aug.	Sept.	Day.	Aug.	Sept.	Day.	Aug.	Sept.
1	3.50	3.35	9	3.50	3.20	17	3.30	3.10	25	3.45	2.90
2	3.50	3.35	10	3.50	3.20	18	3.30	3.10	26	3.40	2.80
3	3.50	3.35	11	3.50	3.30	19	3.30	3.10	27	3.30	2.80
4	3.50	3.35	12	3.50	3.30	20	3.30	3.10	28	3.30	2.80
5	3.50	3.35	13	3.40	3.30	21	3.30	3.00	29	3.35	2.80
6	3.50	3.35	14	3.30	3.20	22	3.30	3.00	30	3.40	2.80
7	3.50	3.30	15	3.30	3.20	23	3.30	3.00	31	3.35	.....
8	3.50	3.20	16	3.40	3.15	24	3.40	2.90			

Daily gage height, in feet, of Arkansas River at Salida, Colorado, for 1898.

Day.	Aug.	Sept.	Oct.	Nov.	Day.	Aug.	Sept.	Oct.	Nov.	Day.	Aug.	Sept.	Oct.	Nov.
1	1.05	0.90	0.70	0.90	12	0.80	0.80	0.80	0.80	23	0.75	0.70	0.90	0.75
2	1.05	.85	.70	.90	13	.80	.80	.70	.80	24	.85	.70	.90	.80
3	.90	.80	.65	.90	14	.80	.80	.70	.80	25	.90	.70	.90	.85
4	.90	.80	.60	.90	15	.80	.80	.70	.80	26	.85	.70	.90	.80
5	.90	.75	.70	.90	16	.80	.75	.70	.80	27	.80	.70	.90	.80
6	.90	.70	.60	.90	17	.80	.70	.70	.80	28	.80	.70	.90	.80
7	.90	.70	.60	.90	18	.90	.70	.80	.80	29	.80	.70	.90	.80
8	1.00	.70	.70	.80	19	.80	.70	.80	.90	30	.75	.70	.90	.90
9	.90	.70	.75	.80	20	.80	.70	.80	.90	31	.70	.....	.90	.....
10	1.00	.70	.80	.80	21	.80	.70	.80	.90					
11	.80	.90	.80	.80	22	.75	.70	.90	.75					

Daily gage height, in feet, of Arkansas River at Canyon, Colorado, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	2.50	.....	.....	.....	2.80	3.85	4.00	2.80	2.30	2.10	2.60	.....
2	.....	.....	.....	2.50	2.90	4.10	3.90	2.80	2.20	2.10	2.50	.....
3	.....	.....	.....	.....	3.05	4.20	3.80	2.70	2.20	2.10	2.50	2.70
4	.....	.....	.....	.....	3.20	4.50	3.70	2.60	2.20	2.10	2.50	.....
5	.....	2.60	2.70	.....	3.30	4.50	3.75	2.60	2.20	2.10	2.50	.....
6	.....	.....	.....	.....	3.40	4.15	3.85	2.50	2.20	2.10	2.50	.....
7	.....	.....	.....	.....	3.50	4.10	4.00	2.40	2.20	2.10	2.50	.....
8	2.50	.....	.....	.....	3.40	4.25	4.20	2.65	2.20	2.10	2.45	.....
9	.....	.....	.....	2.70	3.40	4.35	4.15	2.85	2.20	2.10	2.40	.....
10	.....	.....	.....	.....	3.40	4.25	4.00	2.85	2.30	2.10	2.40	2.70
11	.....	.....	.....	.....	3.30	4.30	4.05	2.80	2.30	2.20	2.40	.....
12	.....	2.60	2.60	.....	3.30	4.35	4.35	2.70	2.30	2.25	2.50	.....
13	.....	.....	.....	.....	3.25	4.40	4.50	2.60	2.30	2.30	2.50	.....
14	.....	.....	.....	.....	3.35	4.35	4.75	2.50	2.30	2.30	2.50	.....
15	2.40	.....	.....	.....	3.40	4.45	4.50	2.50	2.30	2.40	2.50	.....
16	.....	.....	.....	3.00	3.30	4.65	4.75	3.25	2.30	2.40	2.60	.....
17	.....	.....	.....	.....	3.30	4.85	4.50	2.65	2.20	2.40	2.60	a 2.60
18	.....	.....	.....	.....	3.20	5.05	4.30	2.55	2.20	2.40	2.60	.....
19	.....	2.70	2.70	.....	3.15	5.15	3.85	2.50	2.20	2.40	2.60	.....
20	.....	.....	.....	.....	3.10	5.15	3.70	2.50	2.20	2.50	2.60	.....
21	.....	.....	.....	.....	3.05	5.00	3.70	2.50	2.20	2.50	2.60	.....
22	2.40	.....	.....	.....	3.05	5.00	3.60	2.50	2.20	2.50	2.60	.....
23	.....	.....	.....	2.70	3.10	4.90	3.50	2.55	2.20	2.50	2.70	.....
24	.....	.....	.....	.....	3.10	4.80	3.50	2.50	2.20	2.50	2.70	a 2.60
25	.....	.....	.....	.....	3.00	4.75	3.50	2.50	2.20	2.50	2.70	.....
26	.....	2.80	2.60	.....	3.05	4.60	3.40	2.45	2.10	2.50	2.70	.....
27	.....	.....	.....	.....	3.25	4.45	3.30	2.40	2.10	2.50	2.70	.....
28	.....	.....	.....	.....	3.50	4.25	3.15	2.40	2.10	2.50	2.70	.....
29	2.60	.....	.....	.....	3.70	4.15	3.00	2.40	2.10	2.60	2.60	.....
30	.....	.....	.....	2.80	3.90	4.05	3.00	2.40	2.10	2.60	2.60	.....
31	.....	.....	.....	.....	3.90	.....	2.90	2.40	.....	2.60	.....	a 2.60

a Approximate.

Daily gage height, in feet, of Arkansas River at Santa Fe Avenue Bridge, Pueblo, Colorado, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.
1	0.40	0.30	0.45	0.20	0.60	1.20	1.35	0.35
2	.45	.20	.45	.20	.70	1.20	1.20	.35
3	.45	.30	.40	.20	.75	1.50	1.20	.30
4	.40	.40	.40	.30	.85	1.55	1.15	.30
5	.40	.40	.40	.25	.90	1.55	1.00	.35
6	.40	.40	.35	.20	.85	1.50	1.30	.30
7	.40	.50	.30	.20	1.00	1.55	1.35	.45
8	.40	.50	.30	.20	1.10	1.80	1.55	.45
9	.40	.50	.30	.20	1.15	1.80	1.60	.50
10	.40	.45	.30	.20	1.20	1.70	1.45	.45
11	.40	.45	.35	.25	1.00	1.80	1.50	.45
12	.40	.40	.40	.55	.90	1.35	1.50	.30
13	.40	.35	.30	.55	.90	1.80	3.20	.20
14	.35	.40	.30	.45	.95	1.85	2.70	.15
15	.30	.40	.30	.45	.90	2.05	2.20	.20
16	.30	.40	.30	.60	.90	2.10	1.90	.25
17	.30	.50	.30	.65	.95	2.25	2.05	.40
18	.35	.45	.30	.65	.80	2.50	1.70	.35
19	.40	.40	.30	.60	.75	2.70	1.35	.30
20	.35	.40	.30	.50	.65	2.80	1.05	.30
21	.35	.40	.30	.45	.65	2.80	1.05	.25
22	.25	.40	.30	.40	.60	2.55	1.00	.30
23	.15	.40	.35	.35	.60	2.45	1.00	.25
24	.20	.40	.30	.30	.50	2.40	.90	.20
25	.10	.40	.30	.30	.50	2.40	1.10	.25
26	.10	.35	.30	.30	.90	2.35	1.25	.25
27	.30	.45	.30	.30	.90	1.90	.95	.20
28	.25	.40	.30	.30	.75	1.60	.75	.....
29	.25	.....	.30	.55	.85	1.45	.50	.....
30	.40	.....	.30	.50	1.10	1.35	.45	.....
31	.30	.....	.20	.....	1.15	.....	.40	.....

Daily gage height, in feet, of Arkansas River at Main Street Bridge, Pueblo, Colorado, for 1898.

Day.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Day.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	.....	0.50	—0.05	—0.35	0.34	0.37	17	2.10	0.95	0.15	0.26	0.30	0.37
2	.....	.40	+ .05	— .35	.34	.30	18	2.20	.40	.15	.26	.35	.51
3	.....	.40	— .10	— .40	.25	.25	19	1.50	.18	.10	.28	.29	.51
4	.....	.30	— .23	— .40	.25	.25	20	1.40	.18	.20	.32	.30	.50
5	.....	.20	— .18	— .43	.24	.26	21	1.15	.12	— .10	.32	.39	.47
6	.....	.20	— .21	— .44	.22	.31	22	1.10	.10	— .20	.32	.35	.45
7	.....	.50	— .38	— .38	.22	.40	23	.95	.10	— .20	.32	.32	.35
8	.....	.50	— .34	— .30	.25	.10	24	.85	.15	— .17	.32	.35	.34
9	.....	.55	— .21	— .20	.30	.11	25	.95	.15	— .14	.41	.38	.49
10	1.60	.65	— .11	— .10	.30	.27	26	1.30	.12	— .11	.42	.37	.49
11	1.30	.50	+ .15	— .13	.32	.30	27	.80	.06	— .12	.44	.32	.50
12	2.40	.43	.12	— .09	.20	.40	28	.80	.01	— .23	.45	.27	.48
13	4.45	.30	.21	.00	.30	.33	29	.68	.00	— .26	.40	.42	.49
14	3.20	.10	.12	.02	.34	.31	30	.58	.00	— .32	.45	.32	.47
15	3.30	.20	.19	.04	.34	.33	31	.50	—.04	.....	.37	.....	.45
16	2.00	.20	.18	.10	.32	.40							

Daily gage height, in feet, of Arkansas River at Nepesta, Colorado, for 1898.

Day.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.
1	.....	2.80	3.30	3.20	3.00	2.60	2.40	3.20
2	.....	3.10	3.30	3.80	2.90	2.70	2.60	3.15
3	.....	3.00	3.30	3.70	2.80	2.60	2.70	3.15
4	.....	3.40	3.50	3.50	2.70	2.50	2.80	3.10
5	.....	3.10	3.60	3.40	2.60	2.40	2.80	3.10
6	.....	3.10	3.65	3.50	2.50	2.50	2.80	3.10
7	.....	3.10	3.50	3.70	3.05	2.50	2.90	3.00
8	.....	4.30	4.00	3.80	3.20	2.50	2.90	2.90
9	.....	6.00	4.50	4.40	3.30	2.55	2.90	2.90
10	.....	4.20	4.30	4.00	3.30	2.50	2.70	3.05
11	.....	4.00	4.00	3.80	3.20	2.70	2.60	3.05
12	.....	4.00	4.30	3.70	3.10	2.80	2.80	3.10
13	.....	3.60	4.30	4.00	2.60	2.90	2.80	3.10
14	.....	3.50	4.30	6.10	2.10	3.00	2.80	3.20
15	.....	3.40	5.70	5.10	2.80	3.00	2.80	3.15
16	.....	3.45	4.80	4.70	2.90	2.90	2.80	3.10

Daily gage height, in feet, of Arkansas River at Nepesta, Colorado, 1898—Cont'd.

Day.	April.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.
17	.....	3.50	4.80	4.40	2.80	2.90	2.80	3.10
18	.....	3.00	4.80	4.50	3.10	2.90	2.90	3.10
19	.....	3.60	4.80	4.00	3.10	2.90	3.00	3.10
20	.....	3.40	4.80	3.80	2.90	2.90	3.00	3.10
21	.....	3.40	4.70	3.50	2.80	2.90	3.00	3.10
22	.....	3.70	4.80	3.20	2.70	2.90	2.95	3.10
23	.....	3.20	4.80	3.00	3.35	2.90	3.00	3.10
24	.....	2.90	4.80	2.60	3.00	2.90	3.00	3.10
25	.....	2.70	4.50	2.20	2.90	2.90	3.00	3.00
26	2.60	2.50	4.40	3.90	2.90	2.90	3.00	3.00
27	2.55	4.00	4.20	3.70	2.80	3.00	3.10	3.00
28	2.50	3.10	4.60	3.10	3.00	2.80	3.10	3.00
29	2.70	3.10	3.80	3.20	2.80	2.80	3.10	2.90
30	2.80	3.30	3.50	3.10	2.90	2.80	3.20	2.90
31	.....	3.30	.....	3.00	2.60	.....	3.20	.....

Daily gage height, in feet, of Arkansas River at Rocky Ford, Colorado, for 1898.

Day.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	.....	0.90	0.72	1.20	1.02	0.91	1.00	0.74	0.72	1.19	0.81
2	.....	.93	.71	1.25	.95	.96	.93	.79	.70	1.18	.75
3	.....	.93	.82	1.32	1.04	1.35	.93	.69	.65	1.00	.60
4	.....	.98	.92	1.50	1.34	1.50	1.00	.65	.62	.95	.60
5	.....	.95	.79	1.50	1.48	1.40	.90	.60	.62	1.05	.60
6	.....	.92	.70	1.36	1.48	1.32	.81	.60	.60	.92	1.00
7	.....	.90	.70	1.50	1.45	1.35	.80	.55	.60	.91	1.00
8	.....	.92	.72	2.20	2.05	1.60	.96	.54	.65	.90	1.00
9	.....	.98	.70	2.80	2.15	2.80	1.18	.52	.70	.90	1.00
10	.....	.98	.60	2.10	2.25	1.74	1.13	.52	.68	1.18	1.00
11	.....	.98	.52	2.10	2.13	1.55	1.08	.58	.65	.98	1.00
12	.....	.92	.80	2.05	2.38	1.27	1.02	.71	.65	1.00	1.00
13	.....	.89	.97	1.70	2.35	1.55	.95	.75	.84	1.12	.80
14	.....	.89	.85	1.55	2.37	3.15	1.03	.87	.73	1.16	.70
15	.....	.95	.89	1.52	2.85	2.70	1.00	.95	.83	1.20	.70
16	.....	.88	.85	1.38	2.75	2.40	.80	.95	.90	1.20	.75
17	.....	.83	.90	1.33	2.62	2.23	.77	.98	.84	1.20	.70
18	.....	.87	.98	1.25	2.25	2.19	.80	.89	.85	1.22	.....
19	.....	.98	1.10	1.06	2.27	1.75	.83	.88	.98	1.20	.....
20	0.52	1.01	1.11	.90	2.85	1.50	.75	.84	1.00	1.19	.....
21	.42	1.01	1.04	1.60	2.90	1.28	.77	.88	1.03	1.20	.....
22	.30	.88	.98	1.22	2.75	1.20	.79	.80	.88	1.25	.....
23	.41	.80	.93	.94	2.50	1.00	.85	.80	.89	1.25	.....
24	.45	.80	.86	.80	2.40	.85	.78	.80	.94	1.30	.....
25	.45	.80	.81	.70	2.35	1.10	1.05	.83	1.00	1.30	.....
26	.54	.80	.80	3.20	2.15	1.18	.81	.90	1.00	1.20	.....
27	.70	.78	.72	2.02	2.00	1.25	.72	.82	1.05	.98	.....
28	.86	.75	.70	1.40	1.60	1.35	.81	.77	1.05	.80	.....
29	.....	.80	.71	1.25	1.43	1.18	.80	.75	1.05	.60	.....
30	.....	.79	.82	1.15	1.18	1.08	.79	.82	1.12	.74	.....
31	.....	.75	.....	1.15	.....	1.05	.75	.....	1.12	.....	.....

Daily gage height, in feet, of Arkansas River at Manzanola, Colorado, for 1898.

Day.	May.	June.	July.	Aug.	Sept.	Oct.	Day.	May.	June.	July.	Aug.	Sept.	Oct.
1	.....	3.40	3.40	2.40	1.60	2.20	17	.....	4.40	4.40	2.20	2.50	2.40
2	.....	3.40	3.80	2.50	1.00	2.30	18	3.30	4.80	4.00	2.40	2.50	2.50
3	.....	3.50	3.50	2.30	.80	2.30	19	3.30	5.20	3.80	2.30	2.40	2.50
4	.....	3.90	3.40	2.30	.80	2.20	20	2.90	5.20	3.30	2.20	2.40	2.50
5	.....	3.80	3.50	2.20	.80	2.20	21	4.08	5.00	3.00	2.00	2.40	2.60
6	.....	3.70	3.40	2.00	.80	2.20	22	3.30	4.90	2.70	2.00	2.40	2.60
7	.....	3.50	3.40	2.00	2.00	2.20	23	3.20	4.70	2.50	1.90	2.50	.....
8	.....	4.30	4.20	2.60	2.00	2.20	24	2.90	4.60	2.40	1.90	2.50	.....
9	.....	4.00	5.50	2.50	1.90	2.30	25	3.10	4.40	2.50	3.00	2.40	.....
10	.....	4.40	3.90	2.40	1.90	2.30	26	4.55	4.40	3.00	2.80	2.30	.....
11	.....	4.40	4.00	2.40	2.00	2.30	27	4.20	4.30	3.60	2.00	2.30	.....
12	.....	3.70	4.20	2.40	2.20	1.90	28	3.40	4.00	3.00	1.90	2.20	.....
13	.....	3.50	5.20	2.30	2.50	2.40	29	3.30	3.80	2.70	1.90	2.20	.....
14	.....	4.30	6.00	2.30	2.70	2.50	30	3.30	3.50	2.40	1.80	2.20	.....
15	.....	4.00	5.00	2.30	2.80	2.60	31	3.50	.....	2.40	1.60	.....	.....
16	.....	4.40	4.60	2.30	2.80	2.60							

Daily gage height, in feet, of Purgatory River at Trinidad, Colorado, for 1898.

Day.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.
1	3.90	4.00	3.95	3.95	3.50	3.50	3.50
2	3.90	3.95	3.80	3.90	3.55	3.50	3.50
3	3.90	3.90	3.90	3.80	3.50	3.50	3.50
4	3.95	4.00	4.35	4.10	3.50	3.40	3.50
5	4.00	3.90	4.00	4.00	3.50	3.40	3.50
6	4.20	3.90	3.90	3.90	3.50	3.40	3.50
7	4.10	4.00	3.90	4.30	3.50	3.40	3.50
8	4.35	4.00	3.90	4.30	3.50	3.40	3.50
9	4.25	4.00	3.95	4.25	3.50	3.40	3.50
10	4.20	4.05	3.90	4.10	4.00	3.40	3.50
11	4.20	4.05	3.85	4.00	4.50	3.40	3.50
12	4.10	4.00	3.90	3.95	4.50	3.45	3.50
13	4.15	4.10	4.45	3.75	4.50	3.45	3.50
14	4.10	4.30	4.10	3.70	3.50	3.45	3.50
15	4.10	4.05	4.10	3.70	3.50	3.45	3.50
16	4.00	4.05	4.00	3.75	3.50	3.55	3.50
17	4.00	4.00	4.00	3.80	3.50	3.50	3.50
18	3.90	4.35	3.95	3.75	3.50	3.50	3.50
19	3.90	4.50	3.80	3.75	3.50	3.55	3.50
20	3.90	4.40	4.15	3.65	3.50	3.60	3.50
21	3.90	4.35	3.90	3.70	3.50	3.55	3.50
22	3.90	4.25	3.80	3.70	3.50	3.50	3.45
23	3.85	4.20	3.80	3.90	3.50	3.50	3.50
24	3.80	4.20	4.35	3.90	3.50	3.50	3.50
25	3.80	4.10	4.05	3.70	3.50	3.50	3.45
26	3.95	4.00	3.90	3.60	3.50	3.50	3.50
27	3.90	4.00	3.85	3.60	3.50	3.50	3.50
28	3.90	3.85	3.70	3.60	3.50	3.45	3.50
29	3.90	3.80	3.70	3.60	3.50	3.40	3.50
30	3.90	3.80	3.70	3.60	3.50	3.45	3.50
31	4.00	.....	4.05	3.50	.....	3.50	.....

Daily gage height, in feet, of Purgatory River at J. J. Ranch, for 1898.

Day.	June.	July.	Aug.	Sept.	Oct.	Nov.	Day.	June.	July.	Aug.	Sept.	Oct.	Nov.
1	.....	2.20	.....	2.70	2.70	2.70	17	2.90	.....	2.90	2.70	3.00	.....
2	.....	2.20	.....	2.70	2.70	2.70	18	2.50	.....	3.00	2.70	3.00	.....
3	.....	.....	.....	2.70	2.70	2.70	19	2.50	.....	2.90	2.70	2.90	.....
4	.....	.....	.....	2.70	2.50	2.70	20	3.00	.....	2.90	2.70	2.70	.....
5	.....	.....	.....	2.70	2.50	2.70	21	3.50	.....	3.00	2.70	2.70	.....
6	.....	.....	.....	2.70	2.50	2.70	22	2.60	.....	3.00	2.70	2.70	.....
7	.....	.....	5.20	2.70	2.50	2.70	23	2.50	.....	3.00	2.70	2.70	.....
8	.....	.....	5.70	2.70	2.50	2.70	24	2.80	.....	3.00	2.70	2.70	.....
9	.....	.....	4.00	2.60	2.50	2.70	25	2.80	.....	3.00	2.70	2.70	.....
10	.....	.....	3.80	2.70	3.00	2.70	26	2.50	.....	2.80	2.70	2.70	.....
11	.....	.....	3.80	2.70	2.80	2.70	27	2.80	.....	3.00	2.70	2.70	.....
12	.....	.....	3.80	2.70	2.70	2.70	28	2.90	.....	2.70	2.70	2.70	.....
13	2.30	.....	3.00	2.70	2.50	.....	29	2.70	.....	2.70	2.70	2.70	.....
14	2.40	.....	3.30	3.70	2.80	.....	30	2.50	.....	2.70	2.70	2.70	.....
15	2.40	.....	3.40	2.70	2.80	.....	31	.....	.....	2.70	.....	2.70	.....
16	2.95	.....	2.90	2.70	3.00	.....							

Daily gage height, in feet, of Arkansas River at Las Animas, Colorado, for 1898.

Day.	May.	July.	Aug.	Sept.	Oct.	Nov.	Day.	May.	July.	Aug.	Sept.	Oct.	Nov.
1	.....	.....	3.10	2.40	2.30	2.90	17	2.80	.....	3.10	2.40	2.30	.....
2	.....	.....	2.80	2.40	2.30	2.90	18	.....	.....	2.80	2.40	2.30	.....
3	.....	.....	2.70	2.40	2.30	2.90	19	2.75	3.75	2.70	2.40	2.40	.....
4	.....	.....	2.80	2.40	2.30	3.00	20	.....	3.45	2.60	2.40	2.40	.....
5	.....	.....	2.70	2.40	2.30	3.00	21	2.80	3.20	2.60	2.40	2.40	.....
6	.....	.....	2.70	2.30	2.30	2.90	22	2.80	3.10	2.60	2.40	2.75	.....
7	.....	.....	2.80	2.30	2.30	3.00	23	2.80	3.00	2.50	2.40	2.80	.....
8	.....	.....	2.70	2.30	2.30	3.00	24	.....	3.00	2.50	2.40	2.80	.....
9	.....	.....	2.60	2.20	2.30	2.90	25	2.40	2.80	2.50	2.40	2.80	.....
10	.....	.....	2.60	2.30	2.30	2.90	26	2.40	2.70	2.50	2.40	2.90	.....
11	.....	.....	2.50	2.30	2.30	2.90	27	5.50	2.60	2.50	2.40	2.80	.....
12	.....	.....	2.50	2.40	2.30	3.00	28	3.20	2.60	2.50	2.30	2.80	.....
13	3.50	.....	2.50	2.50	2.30	.....	29	.....	2.60	2.50	2.30	2.70	.....
14	3.30	.....	2.50	2.50	2.30	.....	30	.....	2.90	2.50	2.30	2.90	.....
15	3.10	.....	2.50	2.50	2.30	.....	31	.....	3.00	2.50	.....	3.00	.....
16	3.30	.....	2.25	2.50	2.30	.....							

Daily gage height, in feet, of Arkansas River at Amity Canal head gate, for 1898.

Day.	Aug.	Sept.	Oct.	Nov.	Dec.	Day.	Aug.	Sept.	Oct.	Nov.	Dec.
1	3.35	0.55	0.10	1.90	3.00	17	5.50	.60	.40	1.60	2.30
2	2.95	.40	.10	1.90	3.00	18	3.90	.60	.50	1.60	2.30
3	2.10	.30	.10	1.90	3.00	19	2.30	.50	.70	1.60	2.30
4	2.05	.25	.10	1.90	3.00	20	1.75	.40	.90	1.60	2.00
5	1.82	.20	.10	1.90	3.00	21	1.55	.40	.80	1.50	2.00
6	2.20	.15	.10	1.95	3.00	22	1.30	.40	.80	1.00	2.00
7	2.20	.10	.10	1.90	3.00	23	1.30	.40	1.10	2.90	2.00
8	2.40	.10	.20	2.00	2.55	24	2.30	.30	1.30	4.80	2.00
9	3.15	.10	.20	2.00	1.80	25	1.30	.30	1.50	5.00	2.00
10	2.75	.20	.20	2.00	1.90	26	1.15	.30	1.60	5.00	2.00
11	2.05	.20	.20	1.90	1.90	27	1.00	.30	1.70	5.00	2.00
12	1.85	.60	.20	2.00	2.00	28	1.65	.30	1.70	4.00	2.50
13	1.70	.80	.20	2.00	2.15	29	1.35	.20	1.50	3.50	2.50
14	1.60	.80	.20	2.00	2.30	30	1.05	.20	1.40	3.20	2.00
15	1.55	.70	.20	2.00	2.30	31	.80	.....	1.60	.....	2.00
16	1.45	.60	.40	1.90	2.30						

Daily gage height, in feet, of Arkansas River at Granada, Colorado, for 1898.

Day.	July.	Aug.	Sept.	Oct.	Nov.	Day.	July.	Aug.	Sept.	Oct.	Nov.
1	.....	1.20	0.60	0.60	1.00	17	.....	0.60	0.60	0.80	0.60
2	.....	.80	.60	.40	.90	18	.....	1.60	.60	.60	.60
3	.....	.80	.80	.40	.90	19	.....	.80	.80	1.50	.60
4	.....	.60	.80	.40	.90	20	.....	.60	.70	1.50	.....
5	.....	.40	.80	.40	.90	21	.....	.40	.60	1.30	.....
6	.....	.40	.60	.40	.90	22	.....	.60	.60	1.30	.....
7	.....	.40	.60	.40	.90	23	.....	.60	.60	1.30	.....
8	.....	.40	.60	.40	.90	24	0.60	1.00	.60	1.30	.....
9	.....	.40	.60	.60	1.00	25	.60	.90	.60	1.00	.....
10	.....	.40	.80	.60	1.00	26	.80	.60	.60	1.00	.....
11	.....	.40	.80	.60	1.00	27	1.20	.40	.60	.80	.....
12	.....	.40	.80	.60	1.00	28	1.20	.40	.60	.80	.....
13	.....	.40	.60	.60	1.00	29	.80	1.00	.60	.80	.....
14	.....	.20	.60	.60	1.00	30	.60	.80	.60	.80	.....
15	.....	.20	.60	.60	1.00	31	1.00	.40	.....	1.00	.....
16	.....	.30	.60	.80	.60						

Daily gage height, in feet, of Arkansas River at Hutchinson, Kansas, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	1.50	2.10	1.95	1.60	2.55	3.50	3.20	1.90	1.30	1.50	1.30	1.60
2	1.50	2.10	1.90	1.60	2.80	3.60	2.90	1.85	1.20	1.50	1.30	1.55
3	1.50	2.20	1.90	1.60	2.30	3.40	2.90	1.75	1.20	1.50	1.30	1.50
4	1.50	2.30	1.90	1.60	2.20	2.70	2.80	1.75	1.20	1.45	1.30	1.60
5	1.50	2.30	1.90	1.60	2.20	2.60	2.80	1.70	1.20	1.40	1.30	1.60
6	1.50	2.30	1.90	1.70	2.20	2.55	2.80	1.60	1.20	1.40	1.30	1.40
7	1.50	2.40	1.90	1.70	2.20	2.50	2.65	2.05	1.20	1.40	1.30	1.55
8	1.50	2.40	1.90	1.65	2.20	2.70	2.55	2.05	1.20	1.40	1.30	1.50
9	1.60	2.40	1.90	1.60	2.20	2.70	2.45	2.00	1.10	1.40	1.30	1.60
10	1.75	2.55	1.90	1.60	2.10	2.60	2.35	1.90	1.10	1.45	1.30	1.50
11	2.00	2.85	1.90	1.60	2.10	2.60	2.25	1.90	1.35	1.45	1.30	1.50
12	2.00	2.75	1.90	1.60	2.10	2.60	2.20	1.90	1.40	1.40	1.30	1.50
13	2.15	2.70	1.90	1.60	2.00	2.65	2.15	1.90	1.40	1.40	1.30	1.50
14	2.30	2.55	1.85	1.65	2.00	3.80	2.05	1.85	1.40	1.40	1.30	1.60
15	2.40	2.40	1.80	1.60	2.00	3.70	1.90	1.75	1.35	1.30	1.30	1.60
16	2.40	2.40	1.80	1.60	2.00	3.60	2.55	1.70	1.40	1.35	1.30	1.60
17	2.50	2.40	1.80	1.65	2.00	3.55	2.85	1.65	1.50	1.50	1.30	1.60
18	2.60	2.40	1.85	1.70	2.15	3.50	2.80	1.60	1.50	1.40	1.30	1.60
19	2.60	2.30	1.80	1.75	2.15	3.40	2.65	1.55	1.40	1.40	1.30	2.25
20	2.50	2.20	1.75	1.90	2.00	3.35	2.45	1.50	1.40	1.40	1.30	2.50
21	2.50	2.10	1.70	2.00	2.00	3.30	2.35	1.50	1.50	1.40	1.30	2.35
22	2.35	2.10	1.70	2.00	2.00	3.30	2.25	1.50	1.75	1.40	1.30	2.20
23	2.35	2.10	1.70	2.00	2.00	3.45	2.05	1.50	2.05	1.40	1.40	2.00
24	2.20	2.00	1.70	1.90	2.00	3.25	2.00	1.50	2.30	1.40	1.45	1.85
25	2.20	2.00	1.65	1.90	2.00	3.05	2.00	1.50	2.05	1.40	1.55	1.80
26	2.20	2.00	1.60	1.80	2.05	3.10	2.00	1.45	1.95	1.40	1.60	1.80
27	2.20	2.00	1.60	1.80	2.15	3.35	2.00	1.40	1.80	1.40	1.60	1.70
28	2.20	2.00	1.60	1.70	2.20	3.40	2.00	1.40	1.75	1.40	1.70	1.70
29	2.30	.....	1.60	1.70	2.70	3.30	1.95	1.40	1.60	1.40	1.65	1.70
30	2.10	.....	1.60	2.40	3.10	3.20	1.90	1.35	1.60	1.30	1.70	1.70
31	2.10	.....	1.60	.....	3.30	.....	1.90	1.30	.....	1.30	.....	1.70

Daily gage height, in feet, of Verdigris River at Liberty, Kansas, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	1.90	.....	2.40	3.45	5.40	3.50	4.30	12.25	1.80	2.00	2.30	2.90
2	.....	2.40	2.40	3.30	18.85	4.65	3.50	4.90	1.80	2.00	2.30	2.80
3	1.90	.....	2.40	3.20	26.70	4.75	3.50	4.50	1.80	2.00	2.30	2.80
4	.....	2.30	2.30	5.30	31.50	4.10	3.20	3.65	1.70	2.00	2.20	2.80
5	1.90	.....	2.30	7.35	29.00	3.80	3.05	3.30	1.70	2.00	2.20	2.80
6	.....	.....	2.30	5.50	25.00	3.45	2.90	2.95	1.70	2.00	2.20	2.80
7	1.80	2.20	2.30	4.30	12.50	3.60	2.80	3.05	1.70	2.00	2.20	2.70
8	.....	.....	2.30	4.20	7.30	4.80	2.70	5.15	1.65	2.00	2.20	2.70
9	.....	2.20	2.30	3.90	6.50	4.15	3.15	4.75	1.60	2.00	2.10	2.60
10	1.80	.....	2.30	3.60	5.90	5.20	2.90	3.30	1.60	2.00	2.10	2.50
11	.....	16.30	5.70	3.35	5.45	4.15	2.75	3.00	1.60	2.00	2.10	2.50
12	1.80	5.20	11.00	3.25	5.10	4.10	2.70	2.75	8.35	2.00	2.10	2.50
13	.....	.....	5.80	3.20	4.65	6.70	2.70	2.55	7.25	2.00	2.10	2.50
14	2.20	3.90	4.60	3.10	4.60	6.40	2.55	2.45	5.05	1.95	2.20	2.50
15	.....	.....	4.40	3.10	4.60	4.35	2.45	2.35	3.80	1.90	2.30	2.60
16	.....	3.20	4.40	3.05	10.65	9.65	2.40	2.25	3.20	1.90	2.20	2.60
17	2.20	.....	4.35	3.00	11.35	14.10	2.40	2.20	4.40	1.95	2.20	2.60
18	.....	3.00	11.15	3.00	8.05	7.30	2.35	2.15	5.00	2.00	2.20	3.00
19	2.20	.....	9.70	3.00	7.85	7.15	2.20	2.20	4.85	2.15	2.30	14.20
20	.....	.....	5.60	3.00	12.90	6.90	2.20	2.20	4.00	2.65	2.30	16.80
21	2.20	2.70	4.45	2.95	8.40	5.30	2.35	2.20	3.35	2.75	2.30	15.95
22	.....	.....	8.70	4.10	9.45	5.75	2.45	2.15	3.05	3.00	2.90	8.05
23	.....	2.60	5.00	6.35	8.45	8.05	8.85	2.10	2.80	2.90	2.60	5.50
24	2.40	.....	4.10	6.45	5.20	5.10	3.40	2.10	2.55	2.90	4.10	4.90
25	.....	2.50	3.70	5.45	4.55	4.20	2.80	2.10	2.40	2.65	3.60	4.40
26	4.40	.....	3.55	4.70	4.20	3.75	2.60	2.10	2.30	2.70	3.20	4.20
27	.....	.....	4.30	4.15	4.05	12.00	2.60	2.10	2.20	2.45	3.10	4.10
28	2.60	2.50	4.30	3.90	4.15	15.65	2.50	2.10	2.10	2.40	2.70	4.00
29	.....	.....	4.35	3.65	4.00	8.80	2.35	2.05	2.10	2.30	2.70	3.80
30	.....	.....	4.15	3.55	3.90	4.95	2.25	1.90	2.00	2.30	2.70	3.80
31	2.40	.....	3.60	.....	3.65	.....	10.35	1.80	.....	2.30	.....	3.80

Daily gage height, in feet, of Neosho River at Iola, Kansas, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	1.80	1.95	2.25	2.70	11.00	9.40	3.65	2.40	2.50	2.20	2.40	2.90
2	1.80	1.95	2.25	2.80	18.80	8.00	3.45	2.45	2.40	2.20	2.30	2.90
3	1.80	1.95	2.20	2.80	19.50	5.70	3.25	2.75	2.30	2.20	2.30	2.90
4	1.80	1.80	2.15	3.15	19.50	5.15	3.10	3.00	2.30	2.10	2.30	2.90
5	1.80	1.95	2.10	6.85	16.80	4.40	3.00	2.65	2.30	2.10	3.30	2.90
6	1.80	1.80	2.10	4.55	12.30	4.15	2.90	2.25	2.30	2.10	3.75	2.80
7	1.80	1.80	2.10	3.60	7.50	4.00	2.90	2.20	2.20	2.10	3.10	2.80
8	1.80	1.95	2.10	3.25	6.20	4.10	2.90	2.20	2.20	2.10	2.85	2.80
9	1.80	1.95	2.10	3.10	5.70	5.50	2.80	3.35	2.20	2.10	2.75	2.70
10	1.80	6.60	2.20	2.95	4.95	4.85	2.80	4.35	2.20	2.05	2.70	2.70
11	1.80	4.80	7.85	2.85	4.70	7.30	2.80	3.85	2.50	2.00	2.70	2.70
12	1.80	4.20	4.75	2.70	4.30	9.35	2.80	3.80	3.20	2.00	2.60	2.70
13	1.80	2.95	3.30	2.70	4.25	7.80	2.80	3.45	5.80	2.00	2.60	2.80
14	1.80	2.85	3.10	2.60	4.95	5.10	2.80	3.05	3.90	2.00	2.60	2.80
15	1.80	2.90	3.80	2.60	5.50	5.40	2.80	2.85	3.50	2.10	2.50	2.90
16	1.80	2.95	3.30	2.60	17.50	5.30	2.80	2.70	3.40	2.10	2.50	2.80
17	1.80	2.85	3.15	2.55	11.60	5.50	2.70	3.20	4.80	2.25	2.50	2.70
18	1.80	2.80	3.05	2.50	6.10	7.80	2.70	4.50	6.70	5.70	2.50	2.80
19	1.80	2.70	3.35	2.50	5.70	5.80	2.70	4.10	3.85	5.20	2.50	11.50
20	1.80	2.70	3.30	2.50	9.80	5.10	2.70	3.70	3.35	3.80	2.50	13.35
21	1.80	2.55	3.20	2.55	12.35	5.80	3.80	3.35	3.10	3.35	2.60	8.90
22	1.80	2.45	3.15	2.85	12.30	4.70	2.90	3.20	2.90	3.05	5.80	8.85
23	1.80	2.30	3.10	2.70	8.00	5.70	2.75	3.10	2.80	2.80	4.15	7.70
24	1.80	2.25	2.90	2.80	6.45	5.30	2.70	2.95	2.60	2.70	3.30	5.70
25	1.80	2.20	2.75	4.35	5.45	4.20	2.65	2.90	2.50	2.60	3.05	4.60
26	1.85	2.20	3.00	4.75	4.60	5.40	2.60	2.70	2.40	2.60	2.80	4.15
27	2.00	2.10	3.75	4.05	4.10	20.50	2.60	2.60	2.40	2.50	2.70	4.00
28	2.00	2.10	3.70	3.60	4.00	19.00	2.55	2.60	2.30	2.50	2.80	3.90
29	2.00	.....	3.30	3.15	6.45	7.00	2.50	2.60	2.30	2.40	2.90	3.75
30	1.90	.....	2.85	3.60	6.70	4.25	2.45	2.50	2.20	2.40	2.90	3.60
31	1.80	.....	2.85	.....	8.20	.....	2.40	2.50	.....	2.40	.....	3.20

List of discharge measurements, 1898.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
				Feet.	*Sec.-feet.*
July 30	Arkansas River	Granite, Colo	A. L. Fellows	3.50	151
Aug. 26	do	do	do	3.40	112
Oct. 26	do	do	do	3.30	75
Apr. 27	do	Salida, Colo	do	1.10	480
May 20	do	do	do	1.10	445
June 25	do	do	do	3.10	2,352
July 29	do	do	do	1.25	568
Aug. 26	do	do	do	.90	380
Oct. 26	do	do	do	.80	222
May 21	do	Canyon, Colo	do	3.05	608
June 25	do	do	do	4.82	2,880
July 28	do	do	do	3.05	611
Oct. 27	do	do	do	2.60	316
Apr. 5	do	Pueblo, Colo	P. J. Preston	.27	248
Apr. 29	do	do	A. L. Fellows	.60	513
May 5	do	do	C. W. Beach	.90	876
May 30	do	do	do	1.00	1,144
June 3	do	do	do	1.40	1,639
June 9	do	do	A. L. Fellows	1.80	2,008
June 14	do	do	C. W. Beach	1.90	1,987
July 8	do	do	do	1.63	1,727
July 26	do	do	A. L. Fellows	.85	816
July 28	do	do	C. W. Beach	.81	743
Aug. 2	do	do	do	.45	405
Aug. 11	do	do	do	.50	468
Aug. 20	do	do	R. W. Hawley	.15	211
Aug. 30	do	do	A. L. Fellows	.00	134
Oct. 20	do	do	C. W. Beach	.20	290
Oct. 29	do	do	A. L. Fellows	.40	320
Nov. 3	do	do	C. W. Beach	.30	344
Apr. 27	do	Nepesta, Colo	P. J. Preston	2.55	360
May 6	do	do	C. W. Beach	3.05	746
May 10	do	do	do	4.25	1,998
June 6	do	do	do	3.43	1,080
July 28	do	do	do	3.25	573
Aug. 20	do	do	do	2.85	247
Nov. 6	do	do	do	2.93	212
Apr. 17	do	Rocky Ford, Colo	P. J. Preston	.90	237
May 27	do	do	C. W. Beach	1.83	1,692
May 18	do	Manzanola, Colo	do	3.25	847
Sept. 15	do	do	do	2.38	206
Apr. 28	Purgatory River	Trinidad, Colo	A. L. Fellows	3.90	150
July 27	do	do	do	3.90	149
Aug. 6	do	do	do	3.76	101
Aug. 29	do	do	C. W. Beach	3.60	45
Oct. 28	do	do	A. L. Fellows	3.40	31
June 13	do	J. J. Ranch, Colo	do	2.30	37
Aug. 5	do	do	do	3.65	60
May 12	do	2 miles east of Las Animas, Colo.	C. W. Beach	1.50	382
May 20	do	do	do	1.17	119
Feb. 14	Arkansas River	Hutchinson, Kans.	W. G. Russell	2.55	736
Mar. 1	do	do	do	1.90	197
Apr. 26	do	do	do	1.85	96
May 5	do	do	do	2.20	373
May 25	do	do	do	2.00	163
May 31	do	do	do	3.35	1,722
June 1	do	do	do	3.50	2,106
Sept. 15	do	do	do	1.30	34
Oct. 25	do	do	do	1.40	21
Mar. 24	Verdigris River	Liberty, Kans.	E. C. Murphy	4.00	771
Mar. 25	do	do	do	3.80	674
May 19	do	do	do	9.70	5,040
May 20	do	do	do	14.40	8,654
July 12	do	do	do	2.80	261
Mar. 24	Neosho River	Iola, Kans.	do	2.80	400
May 19	do	do	do	5.50	3,427
May 20	do	do	do	10.60	11,213
July 11	do	do	do	2.85	386

Rating tables.

Granite.		Salida.		Canyon.		Pueblo.		Nepesta. *a*		Nepesta. *b*	
Gage height.	Discharge	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height	Discharge.	Gage height.	Discharge.
Feet.	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*
2.80	8	0.6	100	2.0	135	—0.4	38	2.0	168	2.1	127
2.85	10	.7	169	2.1	160	— .3	54	2.1	200	2.2	136
2.90	12	.8	241	2.2	186	— .2	75	2.2	234	2.3	147
2.95	14	.9	314	2.3	213	— .1	102	2.3	270	2.4	160
3.00	17	1.0	387	2.4	242	.0	136	2.4	308	2.5	175
3.05	20	1.1	460	2.5	276	.2	232	2.5	350	2.6	192
3.10	24	.....	.....	2.6	316	.4	330	2.6	396	2.7	212
3.15	35	.....	.....	2.7	360	.6	568	2.7	447	2.8	236
3.20	47	.....	.....	2.8	408	.8	780	2.8	504	2.9	260
3.25	60	.....	.....	2.9	476	1.0	1,006	2.9	568	3.0	294
3.30	75	.....	.....	3.0	560	1.2	1,258	3.0	641	3.2	511
3.35	98	.....	.....	3.1	682	1.4	1,512	3.2	817	3.4	759
3.40	112	.....	.....	3.2	807	1.6	1,766	3.4	1,025	3.6	1,007
3.45	131	.....	.....	3.3	932	1.8	2,020	3.6	1,250	3.8	1,255
3.50	151	.....	.....	3.4	1,057	2.0	2,274	3.8	1,480	4.0	1,503
3.55	171	.....	.....	3.5	1,182	2.5	2,909	4.0	1,710	4.2	1,751
.....	.....	.....	.....	3.6	1,307	3.0	3,544	4.2	1,940	4.4	2,000
.....	.....	.....	.....	3.7	1,432	3.5	4,179	4.4	2,170	4.6	2,250
.....	.....	.....	.....	3.8	1,557	4.0	4,814	4.6	2,400	4.8	2,500
.....	.....	.....	.....	3.9	1,682	4.5	5,449	4.8	2,630	5.0	2,750
.....	.....	.....	.....	4.0	1,807	5.0	6,084	5.0	2,860	5.2	3,000
.....	.....	.....	.....	4.1	1,932	5.5	6,719	5.2	3,090	5.4	3,250
.....	.....	.....	.....	4.2	2,057	6.0	7,354	5.4	3,320	5.6	3,500
.....	.....	.....	.....	4.3	2,182	6.5	7,989	5.6	3,550	5.8	3,750
.....	.....	.....	.....	4.4	2,307	7.0	8,624	5.8	3,780	6.0	4,000
.....	.....	.....	.....	4.5	2,432	7.5	9,259	6.0	4,010	6.2	4,250
.....	.....	.....	.....	4.6	2,557	8.0	9,894	.....	.....	.....	.....
.....	.....	.....	.....	4.7	2,682	.....	.....	.....	.....	.....	.....
.....	.....	.....	.....	4.8	2,807	.....	.....	.....	.....	.....	.....
.....	.....	.....	.....	4.9	2,932	.....	.....	.....	.....	.....	.....

Rocky Ford.		Trinidad.		Amity Canal.		Hutchinson.		Liberty.		Iola.	
Gage height.	Discharge.	Gage height.	Discharge	Gage height.	Discharge.	Gage height.	Discharge.	Gage height	Dis charge.	Gage height.	Discharge.
Feet.	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*
0.3	34	3.4	31	0.0	0	1.1	4	.....	.....	1.8	1
.4	48	3.5	42	.1	6	1 2	10	1.5	0	1.9	25
.5	64	3.6	58	.2	11	1.3	18	2.0	20	2.0	50
.6	84	3.7	81	.3	17	1.4	32	2.5	87	2.2	105
.7	108	3.8	109	.4	23	1.5	44	3.0	256	2.4	170
.8	150	3.9	157	.5	30	1.6	60	3.5	501	2.6	245
.9	237	4.0	230	.6	38	1.7	82	4.0	770	2.8	340
1.0	393	4.1	335	.7	47	1.8	110	4.5	1,073	3.0	455
1.1	550	4.2	492	.8	56	1.9	140	5.0	1,400	3.2	590
1.2	706	4.3	752	.9	66	2.0	188	5.5	1,760	3.4	745
1.3	862	4.4	1,012	1.0	77	2.1	248	6.0	2,160	3.6	920
1.4	1,019	4.5	1,282	1.2	100	2.2	325	7.0	2,980	3.8	1,115
1.5	1,175	.....	.....	1.4	125	2.3	420	8.0	3,800	4.0	1,330
1.6	1,331	.....	.....	1.6	151	2.4	540	9.0	4,620	4.2	1,565
1.7	1,487	.....	.....	1.8	179	2.5	645	10.0	5,440	4.4	1,715
1.8	1,644	.....	.....	2.0	207	2.6	765	11.0	6,260	4.6	1,980
1.9	1,800	.....	.....	2.2	234	2.7	885	12.0	7,080	4.8	2,250
2.0	1,956	.....	.....	2.4	260	2.8	1,000	13.0	7,900	5.0	2,520
2.1	2,113	.....	.....	2.6	284	2.9	1,120	14.0	8,720	6.0	4,150
2.2	2,269	.....	.....	2.8	306	3.0	1,245	15.0	9,540	7.0	6,200
2.3	2,425	.....	.....	3.0	328	3.1	1,385	16.0	10,360	8.0	8,500
2.4	2,581	.....	.....	3.2	352	3.2	1,525	17.0	11,120	9.0	11,200
2.5	2,738	.....	.....	3.4	377	3.3	1,690	18.0	12,150	10.0	14,250
2.6	2,894	.....	.....	3.6	402	3.4	1,885	19.0	13,250	11.0	17,350
2.7	3,050	.....	.....	3.8	430	3.5	2,106	20.0	14,470	12.0	20,450
2.8	3,206	.....	.....	4.0	460	3.6	2,310	21.0	15,890	13.0	23,550
2.9	3,363	.....	.....	4.2	490	.....	.....	22.0	17,370	14.0	26,650
3.0	3,519	.....	.....	4.4	520	.....	.....	23.0	18,850	15.0	29,750
3.1	3,676	.....	.....	4.6	550	.....	.....	24.0	20,330	16.0	32,850
3.2	3,832	.....	.....	4.8	580	.....	.....	.....	.....	17.0	35,950

a Applicable from April 26 to July 14, 1898.
b Applicable from July 15 to November 30, 1898.

WESTERN GULF DRAINAGE.

DESCRIPTION OF RIVER STATIONS.

Dallas station on Trinity River.—This is located at a point 3 miles north of the court-house. It was established by Prof. Thomas U. Taylor on October 1, 1898. The observer is J. M. Bassett, engineer at the Turtle Creek pump house. Observations are made at 6 a. m. and 6 p. m. upon a gage in the well at the pump house. The height of water is indicated by a pointer which slides up and down. The well is connected with the river by a pipe. The top of the well is 99 feet above the city datum. Measurements of discharge are made by wading. The channel is nearly straight both above and below the point of measurement; the right bank is high, and the left bank is low and liable to overflow. The bed of the stream is of gravel, and shifting.

Waco station on Brazos River.—This station is at the Austin Street Bridge, northwest of Waco, being about 75 miles above the station at Lewis. The observer is C. E. Rogers, a watchman, who takes readings at 6 a. m. and 6 p. m. The gage is inclined, the channel straight, the banks high, but the bed of the stream is of shifting sand. Measurements of discharge have been made under the suspension bridge, above the railroad bridge. Under the former, at low water, is a sand bar, which does not affect, however, the reliability of the measurements, as there are then two distinct channels. This is the condition during the greater part of the year.

Lewis station on Brazos River.—This station is about 1¼ miles southwest of Lewis, Texas, at the International and Great Northern Railroad bridge. The observer, J. M. Proctor, post-office, Hearne, Texas, is a bridge watchman, and takes readings at 6 a. m. and 6 p. m. The gage is vertical, fastened to a post of the bridge. The channel is nearly straight, and the water moves with moderate rapidity. The banks are high and the bed of the stream sandy. Since the establishment of the station at Waco this locality has less importance.

Austin station on Colorado River.—Measurements of Colorado River of Texas are made at two points near Austin. The first of these (Station No. 2) is at the Lake McDonald dam, 3 miles west of the city, and the other at a point above the Congress Avenue Bridge, south of the city. Observations of height of water in Lake McDonald above the dam are made by means of a float placed above the bulkhead of the power house and between it and the breakwater. This float is connected by wire to a suitable index in the power house. The table on page 122 gives the average daily reading thus obtained. The values are expressed in plus and minus, according as the water surface is above or below the crest. A similar reading has been kept since September 1, 1895. A measurement above the head of the lake was made on January 8, 1898, at Sulphur Hollow. The water from the tailrace of the power house flows along in front of the toe of the dam

and parallel with it. When the water is below the crest the flow in the tailrace has been determined to be fairly uniform. Measurements of discharge are made from a temporary bridge placed across this race. The following measurements give the flow: January 5, 1898, 226 second-feet; January 6, 230; January 7, 233; January 13, 234; December 21, 298; December 22, 296.

The observations south of the city are made on a vertical gage attached to a bath house. The observer is W. Peterson. The bench mark is on the first flange above the crib work of the north pier of the highway bridge. Its height is 4.78 feet above the zero of the gage. Measurements of discharge are made at a narrow place in the river, about one-fourth of a mile above.

New Braunfels station on Guadalupe River.—This station is about 1 mile east of the town of New Braunfels, Texas, near the highway bridge below the International and Great Northern Railroad bridge. Observations were begun on March 13, 1898. The observer is G. Behnsch, a storekeeper living about 200 yards from the gage. The readings are made at 8 a. m. and 6 p. m. The gage is an inclined rod, marked to vertical feet and tenths. Discharge measurements are made at a point above the railroad bridge, where the river is divided into two channels by an island. The channels are nearly straight, the bed of the stream rocky, and the results are believed to be reliable. The flow is so nearly constant that observations through a year are believed to be sufficient for all purposes. The following discharge measurements have been made by Prof. Thomas U. Taylor: March 12, 1898, gage height 2.00, discharge, 350 second-feet. On December 20, 1898, gage height 1.90, the discharge of the Guadalupe above the junction of Comal and Guadalupe, 1½ miles north of the city, just below the cemetery crossing, was 44 second-feet.

Pecos station on Pecos River.—Observations of height of Pecos River have been made at a point 6 miles above the town of Pecos, on the Texas and Pacific Railway. The observer is Willard H. Denis, water master, and the time of observations 6 a. m. and 6 p. m. Readings are made at two points, one of these being in the river itself, under the flume of the Margueretta Canal, and the other in the flume which carries the water across Pecos River from the right-hand side to the left, as shown on page 62 of Paper No. 13, where is given a view of the flume. The channel at this point is nearly straight, the water sluggish, the banks high, and the bottom sandy and shifting.

High Bridge station on Pecos River.—This station was established on March 17, 1898, and maintained until December 3, 1898, being discontinued on account of the difficulty of access. It is located at the Pecos viaduct of the Southern Pacific Company. This viaduct is 2,180 feet long and the base of the rails are 321 feet above low water. The observer is J. H. King, post-office, Lozier, Pecos County, Texas. He is section foreman on the railroad, and makes observations

at 6 p. m. The gage is vertical, fastened to the bridge pier. The channel is straight and the banks high and rocky. The first measurement, that made March 16, 1898, at a gage height of 1.00, gave a discharge of 388 second-feet.

Del Norte station on Rio Grande.—Described on page 127 of Paper No. 16. Results for 1897 given on page 381 of the Nineteenth Annual Report, Part IV. Observations are made on alternate days.

Embudo station on Rio Grande.—Described on page 128 of Paper No. 16. Results for 1897 given on page 384 of the Nineteenth Annual Report, Part IV.

Rio Grande station on Rio Grande.—Described on page 130 of Paper No. 16. Results for 1897 given on page 386 of the Nineteenth Annual Report, Part IV.

San Marcial station on Rio Grande.—Described on page 131 of Paper No. 16. Results for 1897 given on page 387 of the Nineteenth Annual Report, Part IV.

El Paso station on Rio Grande.—Described on page 132 of Paper No. 16; results given on page 389 of the Nineteenth Annual Report, Part IV. Work at this locality has been carried on by T. M. Courchesne, under the direction of Mr. W. W. Follett, consulting engineer, International (Water) Boundary Commission. A large number of measurements were made during 1898, as shown in the following list. During the months of October and November the water was so low (probably not more than 2 to 3 second-feet) that the meter could not be used during that time.

List of discharge measurements on Rio Grande at El Paso, Texas.

Date.	Gage height.	Discharge.	Date.	Gage height.	Discharge.	Date.	Gage height.	Discharge.
1898.	*Sec.-ft.*	*Sec.-ft.*	1898.	*Sec.-ft.*	*Sec.-ft.*	1898.	*Sec.-ft.*	*Sec.-ft.*
Jan. 3	7.00	458	May 2	11.00	5,218	July 27	8.40	1,891
Jan. 5	7.20	471	May 3	11.40	6,059	July 29	8.00	1,366
Jan. 7	7.60	640	May 5	11.00	4,773	Aug. 3	7.30	813
Jan. 10	7.50	630	May 7	10.40	3,623	Aug. 6	7.20	637
Jan. 12	7.40	513	May 9	9.50	2,547	Aug. 8	7.10	515
Jan. 14	7.60	676	May 14	9.00	1,184	Aug. 11	7.60	803
Jan. 15	7.30	456	May 17	9.10	1,769	Aug. 13	8.50	2,026
Jan. 17	7.30	474	May 19	9.10	1,884	Aug. 16	7.30	649
Jan. 19	7.90	703	May 23	8.80	1,455	Aug. 18	6.70	353
Jan. 22	7.30	440	May 25	8.40	1,071	Aug. 20	6.40	249
Jan. 25	7.30	434	May 27	8.30	958	Aug. 22	6.00	160
Jan. 28	7.10	400	May 30	7.60	627	Aug. 25	5.90	122
Jan. 29	7.00	361	June 2	7.50	522	Aug. 27	5.70	111
Jan. 31	6.70	207	June 4	7.80	605	Aug. 29	6.30	253
Feb. 2	7.10	404	June 6	8.50	1,137	Aug. 31	5.80	122
Feb. 4	8.10	862	June 7	9.50	2,640	Sept. 3	5.40	64
Mar. 2	7.40	661	June 9	9.00	1,961	Sept. 5	5.30	41
Mar. 20	7.40	405	June 11	10.10	3,080	Sept. 7	5.10	23
Mar. 22	7.10	280	June 20	8.90	1,344	Sept. 10	5.20	25
Mar. 24	6.80	182	June 22	8.70	1,238	Sept. 12	5.00	18
Mar. 27	6.60	120	June 24	8.80	1,484	Sept. 15	5.90	185
Mar. 28	6.50	136	June 27	9.80	2,674	Sept. 17	5.50	84
Mar. 31	6.30	99	June 30	9.60	2,153	Sept. 19	5.30	46
Apr. 1	6.30	96	July 2	9.60	1,926	Sept. 21	5.10	30
Apr. 3	6.10	63	July 6	10.40	3,629	Sept. 24	4.70	9
Apr. 16	7.00	286	July 7	11.00	3,860	Dec. 6	5.40	79
Apr. 18	8.80	1,693	July 9	9.50	1,965	Dec. 19	5.50	96
Apr. 21	9.80	2,481	July 12	9.90	3,105	Dec. 21	5.40	75
Apr. 22	10.30	3,093	July 20	13.60	9,791	Dec. 24	5.40	67
Apr. 23	10.50	3,634	July 23	10.00	3,898	Dec. 27	6.10	196
Apr. 29	10.70	4,443	July 25	8.80	2,920	Dec. 29	5.80	125

TABLES OF DAILY GAGE HEIGHT.

Daily gage height, in feet, of Trinity River at Dallas, Texas, for 1898.

Day.	Oct.	Nov.	Dec.	Day.	Oct.	Nov.	Dec.	Day.	Oct.	Nov.	Dec.
1	55.85	54.50	55.80	12	55.15	54.00	54.85	23	55.15	53.00	58.10
2	55.50	54.40	55.75	13	54.85	54.10	54.70	24	55.00	52.90	57.65
3	55.45	54.30	55.55	14	54.65	54.00	54.65	25	54.85	52.85	57.30
4	55.20	54.30	55.45	15	54.50	53.90	54.90	26	54.75	58.20	56.45
5	55.35	54.30	55.25	16	54.55	54.00	55.00	27	54.95	57.15	56.40
6	57.25	54.15	55.10	17	54.45	53.90	55.05	28	54.75	56.60	56.20
7	56.80	54.10	55.10	18	54.30	53.90	57.40	29	54.55	56.25	55.95
8	55.75	54.00	55.20	19	54.35	53.75	62.35	30	54.80	56.05	55.80
9	55.45	53.90	55.20	20	54.60	53.70	65.60	31	54.65	.....	55.65
10	55.35	54.00	55.15	21	54.90	53.60	58.95				
11	55.15	54.00	55.05	22	55.20	53.15	58.35				

Daily gage height, in feet, of Brazos River at Waco, Texas, for 1898.

Day.	Sept.	Oct.	Nov.	Dec.	Day.	Sept.	Oct.	Nov.	Dec.	Day.	Sept.	Oct.	Nov.	Dec.
1	.....	4.40	2.30	2.20	12	.....	2.80	2.60	2.30	23	2.70	2.80	2.20	2.90
2	.....	4.10	2.30	2.20	13	.....	2.80	2.50	2.30	24	2.70	2.80	2.20	2.80
3	.....	3.70	2.30	2.20	14	2.70	2.60	2.40	2.30	25	2.70	2.70	2.30	2.60
4	.....	3.60	2.30	2.20	15	2.70	2.60	2.40	2.30	26	6.50	2.50	2.40	2.50
5	.....	3.50	2.40	2.30	16	2.70	2.50	2.30	2.40	27	5.60	2.50	2.40	2.50
6	.....	3.50	2.30	2.30	17	2.70	2.50	2.30	2.40	28	5.10	2.50	2.40	2.50
7	.....	3.90	2.20	2.20	18	2.70	3.20	2.30	2.50	29	4.90	2.50	2.30	2.50
8	.....	3.30	2.20	2.20	19	2.70	3.30	2.20	3.80	30	4.70	2.40	2.30	2.50
9	.....	3.20	2.40	2.20	20	2.70	3.10	2.20	3.30	31	.....	2.40	.....	2.50
10	.....	3.10	2.50	2.30	21	2.70	2.90	2.40	3.00					
11	.....	3.10	2.50	2.30	22	2.70	2.70	2.30	2.90					

Daily gage height, in feet, of Brazos River at Lewis, Texas, for 1898.

Day.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	.....	7.30	7.75	6.70	7.45	11.90	7.85	8.35	7.35	4.40	4.15
2	.....	7.10	7.95	6.70	7.40	10.40	8.00	9.60	7.00	4.35	4.10
3	.....	7.25	8.30	6.45	7.80	9.75	7.35	9.00	6.70	4.30	4.10
4	.....	7.50	8.55	6.40	8.90	8.80	6.95	8.15	6.45	4.40	4.10
5	.....	7.50	8.75	8.30	7.95	8.80	6.60	7.60	6.00	4.30	4.00
6	.....	7.50	9.30	8.10	7.50	8.45	6.40	7.00	6.00	4.50	4.10
7	.....	7.50	9.55	7.85	7.80	9.50	6.30	6.85	6.10	4.40	4.10
8	.....	7.55	8.55	7.95	9.40	9.00	6.10	6.40	5.90	4.25	4.10
9	.....	7.65	7.70	8.35	9.60	8.15	6.55	5.95	5.80	4.00	4.10
10	.....	7.85	7.45	8.65	8.65	8.00	8.85	5.70	5.60	4.05	4.10
11	.....	7.90	7.75	8.60	9.40	7.65	8.30	5.50	5.40	4.10	4.10
12	.....	7.70	8.20	8.15	11.25	7.20	7.95	5.45	5.30	4.10	4.10
13	.....	7.85	9.80	10.55	17.45	9.20	7.70	5.30	5.15	4.15	4.10
14	.....	9.20	10.75	10.55	20.40	8.70	7.20	5.15	5.00	4.20	4.10
15	.....	9.30	9.25	9.30	17.15	8.15	6.80	5.00	5.05	4.20	4.00
16	.....	8.65	11.00	8.60	16.05	8.45	6.60	5.05	4.90	4.20	4.00
17	.....	8.00	8.55	8.15	13.95	11.40	7.05	5.05	4.60	4.15	4.10
18	.....	7.75	9.25	7.95	13.65	10.10	7.05	4.95	4.60	4.15	5.20
19	.....	7.20	21.20	7.90	13.80	9.20	6.70	4.90	4.75	4.20	6.10
20	.....	7.55	14.00	7.90	15.00	8.70	6.25	4.85	5.15	4.20	6.55
21	.....	7.30	12.10	7.80	16.20	8.20	6.05	4.80	6.00	4.20	6.15
22	7.05	7.45	11.50	8.30	14.10	7.65	5.75	4.80	5.65	4.10	5.85
23	7.50	7.40	11.00	8.90	12.75	11.00	5.60	4.75	5.45	4.10	5.50
24	7.25	7.15	9.35	8.40	12.15	10.05	5.55	4.60	5.00	4.10	5.15
25	7.05	7.15	8.45	11.45	11.25	9.35	5.35	4.65	4.90	4.10	5.00
26	6.90	7.35	7.90	10.50	10.55	8.75	5.25	4.70	4.75	4.15	4.85
27	6.90	7.60	7.50	9.80	9.85	8.45	5.40	7.35	4.60	4.10	4.70
28	6.80	7.85	7.25	9.60	9.20	8.90	6.45	8.90	4.45	4.10	4.50
29	6.70	7.85	7.15	9.10	10.10	9.70	6.45	8.10	4.35	4.10	4.50
30	.....	8.45	6.95	8.45	11.20	8.35	6.35	7.45	4.30	4.15	4.45
31	.....	8.00	.....	7.85	.....	7.75	6.40	.....	4.35	.....	4.40

Daily gage height, in feet, on crest of dam of Colorado River at Austin, Texas, for 1895.

Day.	Aug.	Sept.	Oct.	Nov.	Dec.	Day.	Aug.	Sept.	Oct.	Nov.	Dec.
1	.....	0.45	0.65	0.30	0.30	17	.30	.25	.30	.30	.25
2	.....	.40	.50	.30	.30	18	.30	.25	.30	.30	.20
3	.....	.40	.90	.40	.30	19	.30	.25	.30	.30	.20
4	.....	.40	.85	.20	.30	20	.30	.20	.25	.40	.30
5	.....	.50	.70	.20	.25	21	.30	.15	.25	.40	.30
6	.....	.50	.60	.20	.25	22	.40	.10	.25	.60	.30
7	.....	.45	.55	.20	.25	23	1.20	.15	.25	.80	.35
8	.....	.40	.50	.20	.20	24	1.40	.10	.25	1.00	.40
9	.....	.40	.50	.20	.20	25	1.00	.60	.25	.80	.40
10	.....	.35	.45	.30	.30	26	.80	.50	.25	.60	.35
11	.....	.35	.45	.50	.20	27	.40	.25	.20	.40	.40
12	.....	.35	.40	.60	.20	28	.45	.25	.20	.30	.45
13	0.40	.40	.35	1.00	.25	29	.50	.40	.20	.30	.55
14	.30	.40	.35	.50	.25	30	.50	.80	.25	.40	.55
15	.30	.35	.35	.30	.25	31	.45	.....	.25	.....	.50
16	.30	.25	.30	.30	.25						

Daily gage height, in feet, on crest of dam of Colorado River at Austin, Texas, for 1896.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	0.50	0.90	0.90	0.30	0.50	—0.50	—5.70	0.15	0.30	1.30	1.20	0.30
2	.50	2.20	.80	.10	.45	— .60	—4.00	.10	.30	1.20	.90	.30
3	.45	1.80	.70	.20	.40	— .70	—2.20	.10	.30	1.00	.90	.30
4	.40	1.40	.60	.30	.35	— .80	—1.00	.05	.25	.80	.80	.30
5	.30	1.20	.60	.90	.30	—1.00	— .60	.00	.20	.50	.70	.30
6	.30	1.00	.60	.40	.30	—1.15	— .20	— .10	.15	.40	.70	.30
7	.30	.80	.60	.15	.25	—1.35	+ .50	— .30	.10	.40	.60	.30
8	.30	.80	.60	.90	.40	—1.50	.60	— .40	.05	.30	.40	.40
9	.30	.70	.60	.80	.35	—1.80	.60	— .50	.00	.30	.40	.40
10	.30	.60	.70	.70	.30	—2.00	.50	— .60	— .05	.30	.40	.40
11	.30	.50	.60	.70	.25	—2.20	.45	— .80	— .15	.30	.50	.40
12	.30	.70	.70	1.30	.20	—2.40	.45	—1.00	— .25	.30	.50	.40
13	.30	.60	.70	1.20	.20	—2.60	.50	—1.05	— .35	.40	.45	.40
14	.30	.50	.60	1.20	.20	—2.80	.90	—1.15	— .45	.50	.45	.35
15	.30	.50	.60	1.20	.20	—3.00	2.60	—1.30	— .50	.60	.45	.35
16	.30	.60	.50	1.20	.20	—3.20	2.50	—1.40	— .60	.50	.40	.35
17	.30	.55	.50	1.10	.20	—3.30	2.00	—1.50	— .70	.40	.40	.30
18	.25	.50	.50	.90	.20	—3.50	1.20	—1.90	— .90	.40	.30	.30
19	.25	.45	.50	.60	.20	—3.60	1.00	—2.05	—1.00	1.00	.30	.30
20	.35	.40	.50	.70	.20	—3.70	.90	—2.20	—1.10	1.60	.30	.30
21	.35	.40	.50	.70	.20	—3.80	.80	—2.50	—1.30	1.80	.35	.30
22	.35	.40	.50	.70	.20	—4.00	.75	—2.60	—1.50	1.60	.35	.30
23	.35	.40	.50	.70	.15	—4.20	.70	—2.80	+2.50	2.00	.45	.30
24	.35	1.00	.50	.70	.10	—4.30	.60	—3.10	1.60	3.00	.35	.25
25	.30	1.20	.50	.60	.05	—4.50	.35	— .20	1.10	3.00	.35	.25
26	.30	1.10	.50	.70	.05	—4.80	.30	+1.50	2.70	2.60	.35	.25
27	.30	1.10	.50	.70	.00	—5.00	.20	1.00	2.60	2.00	.35	.25
28	.30	1.00	.40	.60	—.10	—5.20	.20	.60	2.60	1.60	.35	.25
29	.25	1.00	.30	.60	—.20	—5.40	.20	.50	1.80	1.60	.25	.30
30	.35	.....	.30	.50	—.30	—5.60	.15	.40	1.80	2.00	.25	.40
31	.90	.....	.30	.....	—.40	.....	.15	.....	.....	1.60	.....	.....

Daily gage height, in feet, on crest of dam of Colorado River at Austin, Texas, for 1897.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	0.80	0.40	0.25	1.05	0.70	0.35	0.25	0.20	0.30	—0.03	0.50	—2.00
2	2.20	.30	.23	.90	.80	1.10	.20	.18	.25	— .25	.25	—2.40
3	2.00	.30	.23	.80	.70	1.10	.08	.20	.18	— .30	.15	—2.40
4	1.40	.30	.23	.70	.60	1.00	.00	.20	.20	— .35	.12	—2.40
5	1.00	.30	.23	.60	.50	1.20	— .05	.20	.20	— .50	.12	—2.40
6	.80	.40	.23	.50	.50	1.40	— .15	.20	.20	— .65	.12	—2.40
7	.80	.30	.25	.60	.60	1.00	— .28	.18	.35	— .75	.12	—2.40
8	.80	.30	.23	.95	.60	1.35	— .40	.08	.33	— .85	.17	—2.50
9	.60	.30	.23	.90	1.45	1.00	— .65	.00	.20	— .95	.05	—2.60
10	.60	.30	.23	.98	1.93	.83	— .80	— .05	.15	—1.02	.01	—2.60
11	.50	.35	.23	.85	1.40	.78	— .90	— .20	.10	—1.05	— .02	—2.75
12	.40	.30	.25	.80	1.30	.60	—1.08	— .20	.15	—1.20	— .12	—2.65
13	.50	.30	.20	.70	.95	.50	— .60	— .35	.15	—1.40	— .17	—2.75
14	.55	.30	.20	.50	.83	.48	— .25	— .60	.20	—1.47	— .27	—2.90
15	.50	.30	.20	.55	.85	2.00	— .20	— .40	.50	—1.55	— .10	—3.00
16	.40	.33	.20	.60	1.70	1.85	.00	.....	.65	—1.35	— .07	—3.07
17	.40	.35	.45	.60	1.43	1.98	.15	.....	.60	.00	— .10	—3.15
18	.50	.35	.63	.50	1.10	1.83	.20	— .40	.60	.30	— .10	—3.15
19	.40	.28	.60	.50	.93	1.08	.20	+1.15	.50	.60	— .12	—3.00
20	.40	.30	.60	.50	1.20	.80	.50	1.45	.40	.57	— .40	—3.00
21	.40	.30	.50	.40	1.53	.73	.40	1.30	.40	.55	— .60	—3.15
22	.40	.30	.45	.30	.98	.58	.35	.85	.35	.50	— .65	—2.90
23	.40	.30	.40	.30	1.05	.45	.30	.80	.30	.57	— .70	—3.00
24	.40	.25	.40	.30	.70	.40	.25	.78	.28	.55	— .70	—2.90
25	.40	.25	.35	.30	.55	.38	.20	.65	.18	.50	— .70	—2.90
26	.40	.23	.40	.30	.50	.40	.60	.50	.15	.15	—1.37	—2.80
27	.40	.23	.30	.30	.48	.35	.40	.48	.15	.80	—1.55	—2.70
28	.40	.23	.85	.40	.40	.28	.50	.35	.10	.85	—1.60	—2.70
29	.40	.....	2.40	.35	.45	.28	.45	.40	.05	.65	—1.80	—2.70
30	.30	.....	2.80	.30	.40	.28	.38	.33	.03	.55	—2.00	—2.70
31	.30	.....	1.70	.....	.40	.....	.30	.30	.....	.55	.....	—2.00

Daily gage height, in feet, on crest of dam of Colorado River, at Austin, Texas, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	—2.30	—1.60	0.20	—1.10	0.2	0.20	1.70	0.20	0.50	0.30	—3.90	—5.30
2	—2.30	—1.60	.20	—1.10	.30	.10	1.00	.20	.40	.30	—4.10	.....
3	—2.30	—1.60	.10	—1.30	.30	.10	.80	.20	.30	.20	—4.40	.....
4	—2.20	—1.50	.10	—1.20	.40	.10	.70	.10	.30	.10	—4.60	.....
5	—2.50	—1.50	.10	—1.30	.40	.10	1.10	.10	.30	.10	—4.80	.....
6	—2.50	—1.50	.05	—1.50	.30	.50	.70	.10	.20	.05	—5.00	.....
7	—2.50	—1.50	.05	—1.50	1.20	.00	.60	—.05	.20	.30	—5.20	—6.30
8	—2.50	—1.50	.00	—1.70	1.50	.00	.50	—.15	.10	.30	—5.50	—6.60
9	—2.50	—1.30	.00	—1.80	1.20	1.50	.50	—.10	.10	.20	—5.70	—6.80
10	—2.50	—1.10	.00	—2.00	.80	.90	.30	—.20	.10	.10	—5.90	—7.30
11	—2.40	— .50	.00	—2.00	.60	1.00	.40	—.30	.00	— .10	—5.90	—7.70
12	—2.40	— .20	.00	—1.90	.50	1.70	.40	—.30	— .10	.00	—5.70	—7.50
13	—2.40	.03	.00	+ .80	2.10	1.70	.30	.00	— .30	— .20	—4.70	—7.60
14	—2.40	.20	.00	1.80	2.20	2.30	.40	.70	— .40	— .30	—4.20	—7.40
15	—2.50	.20	.00	1.10	1.20	3.70	.40	.80	— .70	— .50	—3.80	—7.40
16	—2.50	.20	.00	.90	.90	4.20	.30	.70	— .80	— .60	—3.90	—7.40
17	—2.40	.50	.00	.70	.70	3.60	.80	.70	—1.00	— .50	—4.00	—8.00
18	—2.50	.40	.00	.80	.50	2.60	.30	.50	—1.20	— .90	—3.60	—7.30
19	—2.40	.40	.00	1.50	.50	3.90	.10	.50	—1.50	—1.00	—3.50	—7.10
20	—2.30	.40	.00	1.60	.40	4.00	.20	.05	—1.60	—1.30	—3.00	—6.90
21	—2.30	.30	.00	1.10	.40	3.40	.20	.00	—1.90	—1.80	—4.00	—6.60
22	—2.20	.20	.00	.90	.30	1.70	.40	—.10	—2.10	—1.50	—4.20	—6.50
23	—2.20	.30	— .10	.70	.30	1.40	.30	—.30	—2.50	—1.70	—4.30	—6.50
24	—2.10	.20	— .20	.50	.30	1.10	.30	—.40	+2.00	—2.00	—4.60	—6.30
25	—2.00	.20	— .30	.50	.30	.90	.30	—.50	1.70	—2.20	—4.40	—6.10
26	—1.90	.20	— .50	.40	.40	.70	.30	—.70	.90	—2.50	—4.60	—6.00
27	—1.90	.20	— .70	.30	.40	.70	.30	—.70	.70	—2.60	—4.70	—5.80
28	—1.80	.20	— .70	.30	.40	.70	.30	—.60	.50	—2.80	—4.80	—5.80
29	—1.80	.....	— .90	.30	.40	.70	.20	+.70	.40	—3.00	—4.80	—5.70
30	—1.70	.....	— .90	.20	.30	.80	.10	1.40	.30	—3.50	—4.90	—6.10
31	—1.70	.....	—1.00	.....	.20	.....	.20	1.30	.....	—3.60	.....	—5.80

Daily gage height, in feet, of Colorado River above Congress Avenue Bridge, at Austin, Texas, for 1898.

Day.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	.....	2.10	1.95	2.25	2.00	4.10	1.95	2.55	2.35	1.95	1.90
2	.....	2.20	1.95	2.40	2.00	3.70	2.10	2.45	2.30	1.85	1.85
3	.....	2.15	1.95	2.40	2.00	3.20	2.25	2.55	2.25	1.95	1.90
4	.....	2.00	2.00	2.65	2.05	3.05	2.10	2.35	2.10	1.95	1.85
5	.....	2.00	1.95	2.40	2.05	3.05	2.15	2.45	2.05	1.95	1.75
6	.....	1.95	2.00	2.45	1.95	2.90	2.10	2.40	2.05	1.95	1.85
7	.....	1.90	1.95	3.65	1.95	2.85	1.95	2.30	2.25	1.95	1.90
8	.....	1.90	1.95	4.85	2.45	2.70	1.95	2.30	2.40	1.95	2.05
9	.....	1.95	1.95	3.90	4.00	2.55	2.00	2.10	2.25	2.00	2.00
10	.....	1.90	2.00	3.20	3.05	2.50	2.05	2.05	2.05	1.95	2.05
11	.....	2.00	2.00	2.85	4.10	2.55	2.05	2.05	2.00	2.00	2.05
12	.....	1.95	2.05	2.55	4.30	2.40	2.10	2.05	2.05	1.95	1.95
13	.....	1.95	3.40	7.60	4.50	2.35	2.35	2.00	2.20	1.95	1.85
14	.....	1.90	5.05	5.75	6.30	2.70	2.65	1.95	1.90	1.95	2.05
15	2.00	1.95	3.75	4.00	9.55	2.55	2.55	1.95	1.95	2.00	2.00
16	2.45	2.00	3.35	3.50	10.70	2.45	2.40	1.95	1.95	1.85	1.85
17	2.75	1.95	3.00	3.15	8.80	2.20	2.30	1.90	2.00	1.85	1.95
18	2.55	2.00	3.30	2.90	7.40	2.10	2.20	2.00	2.05	1.85	1.85
19	2.50	1.95	3.25	2.70	10.20	2.15	2.15	2.00	2.05	1.85	1.85
20	2.45	1.95	4.75	2.50	9.60	2.05	2.00	2.00	2.05	1.80	1.90
21	2.35	1.95	4.60	2.40	6.10	2.35	1.95	2.00	2.15	1.85	1.95
22	2.30	2.00	3.80	2.45	5.00	2.60	1.95	2.05	2.00	1.90	1.90
23	2.30	1.95	3.20	2.25	4.10	2.55	2.00	5.25	2.05	1.85	1.85
24	2.20	1.95	2.90	2.15	3.75	2.35	2.05	4.40	2.00	1.95	1.90
25	2.20	2.00	2.50	2.15	3.40	2.30	2.05	4.15	1.85	1.95	1.85
26	2.20	2.00	2.45	2.20	3.15	2.20	2.05	3.60	1.85	1.85	1.90
27	2.10	1.90	2.35	2.30	3.05	2.10	2.15	3.10	1.95	1.85	1.95
28	2.05	2.10	2.35	2.20	3.15	2.15	2.70	2.95	2.00	1.90	2.00
29	.....	2.00	2.30	2.15	3.30	2.00	2.90	2.60	1.50	1.90	1.90
30	.....	2.00	2.30	2.05	3.40	1.95	3.60	2.45	2.20	1.85	1.90
31	.....	1.95	.....	2.00	.....	1.95	2.95	.....	1.95	.....	1.85

Daily gage height, in feet, of Guadalupe River at New Braunfels, Texas, for 1898.

Day.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	.....	2.00	2.10	2.00	2.25	2.00	2.20	2.00	2.00	2.00
2	.....	2.00	2.10	2.00	2.40	2.00	2.15	2.00	2.00	2.00
3	.....	2.00	2.10	2.00	2.30	2.00	2.10	2.00	2.00	2.00
4	.....	2.00	2.10	2.00	2.10	2.00	2.05	2.00	2.00	2.00
5	.....	2.00	2.10	2.00	2.10	2.00	2.00	2.00	2.00	2.00
6	.....	2.00	2.10	2.25	2.00	2.00	2.00	2.00	2.00	2.00
7	.....	2.00	2.10	2.10	2.00	2.00	2.00	2.00	2.00	2.00
8	.....	2.00	2.10	2.10	2.00	2.00	2.00	2.00	2.00	2.00
9	.....	2.00	2.10	2.35	2.00	2.00	2.00	2.00	2.00	2.00
10	.....	2.00	2.10	2.30	2.00	2.00	2.00	2.00	2.00	2.00
11	.....	2.00	2.10	2.40	2.00	2.00	2.00	2.00	2.00	2.00
12	.....	2.10	2.10	3.10	2.00	2.00	2.00	2.00	2.00	2.00
13	2.00	2.05	2.10	3.60	2.00	2.00	2.00	2.00	2.00	2.00
14	2.00	2.00	2.10	3.50	2.00	2.00	2.00	2.00	2.00	2.00
15	2.00	2.08	2.10	2.90	2.00	2.00	2.00	2.00	2.00	2.00
16	2.00	2.13	2.10	2.65	2.00	2.00	2.00	2.00	2.00	2.00
17	2.00	2.30	2.10	2.55	2.00	2.00	2.00	2.00	2.00	2.00
18	2.00	2.30	2.10	2.45	2.00	2.00	2.10	2.00	2.00	2.00
19	2.00	2.20	2.10	2.40	2.00	2.00	2.00	2.00	2.00	2.00
20	2.00	2.20	2.10	2.50	2.00	2.05	2.00	2.00	2.00	1.90
21	2.00	2.20	2.10	2.40	2.00	2.00	2.00	2.00	2.00	1.80
22	2.00	2.20	2.25	2.35	2.00	2.00	2.00	2.00	2.00	1.80
23	2.00	2.20	2.10	2.30	2.00	2.00	2.00	2.00	2.00	1.80
24	2.00	2.20	2.10	2.25	2.00	2.00	2.00	2.00	2.00	1.80
25	2.00	2.20	2.10	2.10	2.00	2.00	2.00	2.00	2.00	1.80
26	2.00	2.15	2.00	2.00	2.00	2.00	2.00	2.00	2.00	1.80
27	2.00	2.10	2.00	2.00	2.00	2.05	2.00	2.00	2.00	1.80
28	2.00	2.10	2.00	2.05	2.00	2.00	2.00	2.00	2.00	1.80
29	2.00	2.10	2.00	2.15	2.00	2.00	2.00	2.00	2.00	1.80
30	2.00	2.10	2.00	2.00	2.00	2.40	2.00	2.00	2.00	1.80
31	2.00	.....	2.00	.....	2.00	2.25	.....	2.00	.....	1.80

Daily gage height, in feet, of water in flume of Margueretta Canal, over Pecos River, for 1898.

Day.	Jan.	Mar.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	1.50	1.50	1.50	2.30	1.80	1.70	1.95	2.20
2	1.50	1.50	1.70	2.30	1.80	1.80	1.95	2.20
3	1.50	1.50	1.70	2.30	1.80	1.70	1.95	2.20
4	1.50	1.50	1.70	2.30	1.80	1.70	1.95	2.13
5	1.50	1.50	1.80	2.30	1.80	1.70	1.95	2.10
6	1.50	1.50	1.50	2.30	1.80	1.70	1.95	2.10
7	1.50	1.50	1.80	2.30	1.80	1.75	1.95	2.10
8	1.50	1.50	1.70	2.30	1.80	1.75	2.00	2.10
9	1.50	1.50	1.70	2.20	1.70	1.70	2.00	2.15
10	1.50	1.50	1.70	2.00	1.80	1.70	2.00	2.20
11	1.50	1.50	1.50	2.00	2.10	1.75	2.00	2.10
12	1.50	1.50	1.50	2.00	2.20	1.80	2.00	2.15
13	1.50	1.50	1.70	2.00	2.20	1.80	2.10	2.20
14	1.50	1.50	1.80	2.00	2.20	1.80	2.10	2.20
15	1.50	1.50	1.90	2.00	2.00	1.80	2.15	2.20
16	1.50	1.50	1.80	2.00	2.00	1.80	2.20	2.18
17	1.50	1.50	1.70	2.00	1.80	1.80	2.20	2.15
18	1.50	1.50	1.80	1.90	1.80	1.85	2.20	2.15
19	1.50	1.50	1.80	1.90	1.80	1.85	2.20	2.18
20	1.50	1.50	1.80	1.90	1.80	1.85	2.20	2.15
21	1.50	1.50	1.90	1.90	1.90	1.85	2.15	2.10
22	1.50	1.50	2.10	1.80	1.90	1.90	2.10	2.10
23	1.50	1.50	2.20	1.80	1.60	1.90	2.10	2.10
24	1.50	1.50	2.20	1.80	1.70	1.90	2.10	2.10
25	1.50	1.50	2.10	1.50	1.70	1.90	2.20	2.15
26	1.50	1.50	2.10	1.60	1.70	1.90	2.23	2.20
27	1.50	1.50	2.20	1.70	1.70	1.90	2.20	2.15
28	1.50	1.50	2.30	1.90	1.70	1.90	2.20	2.05
29	1.50	1.50	2.30	1.80	1.70	1.90	2.20	1.95
30	1.50	1.50	2.30	1.90	1.70	1.90	2.20	1.80
31	1.50	1.50	2.30	1.80	.....	1.90	.....	1.80

Daily gage height, in feet, of Pecos River, under flume 6 miles above Pecos, Texas, for 1898.

Day.	Jan.	Mar.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	1.10	1.00	1.40	4.80	2.40	1.80	1.70	1.80
2	1.00	1.00	1.60	4.70	2.30	1.80	1.70	1.70
3	1.00	1.00	1.50	4.70	2.00	1.80	1.70	1.70
4	1.00	1.00	2.80	4.50	2.00	1.80	1.70	1.65
5	1.20	1.00	5.80	4.50	2.00	1.80	1.70	1.60
6	2.00	1.00	6.00	4.20	2.00	1.80	1.70	1.60
7	2.70	1.00	6.50	4.20	2.50	1.80	1.65	1.60
8	3.00	1.00	8.90	6.30	2.20	1.75	1.70	1.65
9	2.80	1.00	9.90	8.80	2.00	1.80	1.70	1.65
10	2.80	1.00	10.70	6.50	2.00	1.80	1.70	1.65
11	2.80	.80	8.00	5.70	2.40	1.90	1.70	1.50
12	2.70	.70	7.00	5.30	2.30	1.90	1.70	1.60
13	2.70	.80	6.20	5.00	2.40	1.80	1.75	3.10
14	2.30	1.00	8.00	4.50	2.30	1.80	1.75	3.20
15	1.80	1.00	11.20	4.50	2.10	1.75	1.75	3.10
16	1.50	1.00	10.80	4.70	2.00	1.70	1.75	3.05
17	1.50	.90	9.00	4.50	2.00	1.70	1.80	3.00
18	1.70	.90	7.00	4.00	2.00	1.70	1.80	3.10
19	1.80	.80	6.00	3.00	2.00	1.65	1.80	3.10
20	2.00	.80	5.50	2.00	2.00	1.65	1.80	3.15
21	2.30	.70	7.00	1.50	2.00	1.70	1.80	3.80
22	2.20	.70	8.20	2.50	2.00	1.70	1.80	3.80
23	2.10	.70	8.00	2.50	2.00	1.70	1.75	3.70
24	2.00	.60	7.50	2.30	1.90	1.70	1.80	3.60
25	2.00	.60	6.80	2.40	1.90	1.70	1.80	4.30
26	1.90	.60	5.80	2.70	1.90	1.70	1.85	4.60
27	1.90	.60	5.00	2.00	1.90	1.70	1.85	4.60
28	1.90	.60	5.00	2.30	1.90	1.70	1.85	4.05
29	1.90	.60	4.90	2.00	1.90	1.70	1.86	3.75
30	1.90	.60	4.80	2.00	1.90	1.70	1.85	3.10
31	1.90	.60	4.80	2.00	.....	1.70	.....	2.85

Daily gage height, in feet, of Pecos River at High Bridge for 1898.

Day.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	.....	1.00	0.70	0.50	1.10	2.20	1.90	0.80	0.60	0.60
2	.....	1.00	.60	.50	1.00	2.10	1.90	.80	.70	.50
3	.....	1.00	.60	.50	1.20	2.80	1.90	.80	.80	.50
4	.....	1.00	.60	.50	1.80	2.40	1.80	.70	.80	.....
5	.....	1.00	.60	.50	1.30	2.20	1.80	.70	.80	.....
6	.....	1.00	.60	.60	1.30	1.90	1.70	.60	.80	.....
7	.....	1.00	.60	.70	1.30	2.10	1.70	.70	.80	.....
8	.....	1.00	.60	.70	1.20	2.50	1.60	.70	.70	.....
9	.....	1.00	.60	.90	1.20	2.20	1.50	.80	.70	.....
10	.....	1.00	.80	.90	1.30	1.90	1.50	.80	.70	.....
11	.....	1.10	.70	.90	2.10	2.00	1.50	.70	.80	.....
12	.....	1.00	.70	1.00	2.50	2.40	1.40	.60	.80	.....
13	.....	1.00	.60	1.10	2.90	2.50	1.30	.60	.80	.....
14	.....	.90	.60	1.40	2.90	2.80	1.30	.50	.70	.....
15	.....	1.00	.60	1.70	3.10	3.00	1.30	.50	.70	.....
16	1.00	1.10	.60	1.80	3.10	3.10	1.20	.50	.60	.....
17	1.10	.90	.60	3.90	3.20	2.90	1.20	.50	.60	.....
18	1.10	.90	.70	2.80	3.20	2.80	1.30	.70	.60	.....
19	1.00	.80	.70	1.80	3.40	2.40	1.30	.70	.60	.....
20	1.00	.80	.70	1.80	3.40	2.20	1.30	.60	.60	.....
21	1.00	.70	.70	1.20	3.20	2.10	1.30	.60	.50	.....
22	1.10	.70	.80	1.10	3.00	2.00	1.30	.60	.50	.....
23	1.10	.70	.80	1.00	2.80	1.90	1.20	.60	.50	.....
24	1.00	.70	.70	.90	2.60	1.90	1.10	.60	.60	.....
25	1.00	.70	.70	.90	2.30	1.90	1.00	.50	.60	.....
26	1.00	.70	.60	.90	2.00	2.10	1.00	.50	.70	.....
27	1.00	.70	.60	1.70	1.90	2.40	.90	.40	.70	.....
28	1.00	.80	.60	1.40	1.90	2.10	.90	.40	.70	.....
29	1.00	.80	.60	1.20	1.80	2.00	.80	.40	.60	.....
30	1.10	.80	.60	1.10	1.80	2.00	.80	.60	.60	.....
31	1.00	.....	.50	.....	2.20	1.90	.....	.60	.....	.....

Daily gage height, in feet, of Rio Grande at Del Norte, Colorado, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	2.72	.....	.....	2.48	4.06	4.96	3.56	2.00	1.66	1.48	1.54	2.70
3	.....	.....	.....	2.34	3.52	5.30	3.20	1.98	1.70	1.48	1.46	2.72
5	.....	2.96	2.86	2.38	3.60	4.96	3.28	1.94	1.64	1.48	1.46	.....
7	.....	.....	.....	2.62	3.48	5.10	3.74	1.98	1.62	1.48	1.48	.....
8	2.84	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....
9	.....	.....	.....	2.88	3.52	4.64	3.56	2.00	1.60	2.00	1.44	.....
10	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	2.84
11	.....	.....	.....	2.92	3.56	4.28	3.34	1.96	1.64	1.96	1.46	.....
12	.....	2.80	2.98	.....	.....	.....	.....	.....	.....	.....	.....	.....
13	.....	.....	.....	3.00	3.60	4.52	3.38	1.88	1.62	1.88	1.50	.....
14	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	(a)
15	2.88	.....	.....	3.32	3.68	4.86	3.32	1.84	1.60	1.84	1.66	.....
17	.....	.....	.....	3.54	3.64	5.20	3.12	1.86	1.60	1.50	2.74	2.84
19	.....	3.00	2.82	3.46	3.58	4.96	2.92	1.84	1.56	1.46	2.46	.....
21	.....	.....	.....	3.42	3.42	5.00	2.78	1.80	1.54	1.44	2.90	.....
22	2.90	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	(a)
23	.....	.....	.....	3.64	3.54	5.06	2.56	1.76	1.52	1.48	2.76	.....
24	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	.....	2.78
25	.....	.....	.....	3.72	3.66	4.78	2.46	1.74	1.50	1.50	2.88	.....
26	.....	2.94	3.26	.....	.....	.....	.....	.....	.....	.....	.....	.....
27	.....	.....	.....	3.96	4.02	4.28	2.42	1.72	1.50	1.50	2.78	.....
29	2.86	.....	.....	4.20	4.70	3.84	2.18	1.70	1.50	1.46	2.76	.....
31	.....	.....	2.64	.....	4.78	.....	2.12	1.68	.....	1.46	.....	2.72

a Ice.

Daily gage height, in feet, of Rio Grande at Embudo, New Mexico, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	8.40	8.00	8.35	8.50	11.05	10.95	10.20	8.95	7.70	7.70	7.75	7.75
2	8.30	8.00	8.30	8.60	11.00	11.00	10.00	8.85	7.70	7.60	7.80	7.80
3	8.30	8.00	8.25	8.60	10.95	11.05	9.90	8.80	7.70	7.50	7.85	7.80
4	8.30	8.00	8.25	8.65	10.70	11.50	9.55	8.60	7.70	7.50	7.90	7.80
5	8.30	8.00	8.35	8.70	10.50	11.70	9.70	8.60	7.70	7.50	7.90	7.80
6	8.30	8.00	8.40	8.80	10.40	11.70	9.55	8.60	7.70	7.50	7.90	7.80
7	8.20	8.00	8.45	8.90	10.35	11.60	9.50	8.60	7.70	7.50	7.90	7.80
8	8.20	8.00	8.50	8.90	10.25	11.60	9.80	8.40	7.70	7.50	7.90	7.80
9	8.20	8.00	8.60	8.95	10.15	11.40	10.20	8.40	7.70	7.80	7.90	7.80
10	8.20	8.00	8.60	9.00	10.00	11.30	10.45	8.30	7.90	7.80	7.90	7.80
11	8.20	8.00	8.70	9.40	9.95	11.25	10.30	8.00	7.90	7.75	7.90	7.80
12	8.30	8.00	8.75	9.80	9.80	11.05	10.35	8.00	7.90	7.70	7.90	7.80
13	8.30	8.00	8.85	9.95	9.70	10.90	11.20	7.90	7.90	7.60	7.90	7.90
14	8.20	8.00	8.80	10.10	9.65	10.60	11.30	8.00	7.90	7.60	7.95	7.90
15	8.30	8.00	8.75	10.40	9.60	10.50	11.10	8.00	7.90	7.60	7.90	7.90
16	8.30	8.00	8.70	10.60	9.60	10.30	11.70	7.90	7.90	7.55	7.95	7.90
17	8.25	8.00	8.60	10.90	9.65	10.30	11.55	7.90	7.90	7.50	8.00	7.90
18	8.00	8.00	8.50	11.00	9.80	10.50	11.90	7.90	7.80	7.50	8.00	7.90
19	8.00	8.05	8.55	11.00	9.70	10.75	11.80	7.90	7.80	7.50	7.90	7.90
20	8.00	8.10	8.60	11.00	9.65	11.10	11.55	7.80	7.80	7.50	7.85	7.90
21	7.95	8.15	8.55	11.05	9.80	11.45	11.50	7.70	7.80	7.50	7.75	7.80
22	7.90	8.20	8.50	11.10	9.70	11.40	11.00	7.70	7.80	7.50	7.70	7.80
23	7.95	8.25	8.50	11.10	9.70	11.30	10.70	7.70	7.80	7.50	7.70	7.75
24	8.00	8.35	8.60	10.85	9.60	11.30	10.40	7.70	7.80	7.50	7.60	7.75
25	8.00	8.40	8.55	10.80	6.55	11.20	10.10	7.70	7.70	7.55	7.60	7.70
26	8.00	8.35	8.55	10.90	9.60	11.20	9.90	7.70	7.70	7.60	7.60	7.60
27	8.00	8.50	8.60	10.95	9.85	11.00	9.55	7.70	7.70	7.60	7.60	7.60
28	8.00	8.50	8.60	10.80	10.20	10.85	9.15	7.70	7.70	7.60	7.70	7.55
29	8.00	.....	8.50	10.80	10.35	10.60	8.95	7.70	7.70	7.60	7.70	7.50
30	8.00	.....	8.50	10.80	10.50	10.35	8.70	7.70	7.70	7.70	7.70	7.50
31	8.00	.....	8.50	.....	10.85	.....	9.10	7.70	.....	7.70	.....	7.50

Daily gage height, in feet, of Rio Grande at Rio Grande, New Mexico, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	4.95	4.95	5.50	5.25	8.90	7.75	6.35	5.30	4.65	4.50	5.00	6.00
2	4.95	4.95	5.38	5.15	8.20	7.75	6.00	5.30	4.80	4.50	5.00	6.00
3	4.95	4.90	5.30	5.15	8.10	7.65	6.00	5.05	4.90	4.60	5.20	5.80
4	5.10	4.90	5.30	5.30	7.75	7.65	5.85	4.85	5.65	4.60	5.30	5.80
5	5.20	5.00	5.40	5.35	7.65	7.90	5.95	4.80	5.55	4.60	5.40	5.60
6	5.05	5.00	5.45	5.50	7.35	8.10	5.75	4.80	5.50	4.60	5.40	5.55
7	5.10	5.10	5.40	5.70	7.20	7.70	7.15	4.70	4.35	4.60	5.30	5.55
8	5.10	5.15	5.40	5.70	7.20	7.55	7.10	6.70	4.30	4.60	5.40	5.60
9	5.00	5.20	5.45	5.85	7.20	7.55	7.55	6.90	4.30	5.60	5.40	5.50
10	5.00	5.10	5.50	6.20	7.25	7.55	6.75	6.50	5.25	5.50	5.40	5.40
11	5.05	5.05	5.65	6.85	7.25	7.55	6.65	5.95	5.15	5.30	5.40	5.40
12	5.25	5.10	5.70	7.25	7.30	7.50	6.45	5.60	4.95	5.20	5.50	5.40
13	5.15	5.15	5.65	7.70	7.30	7.45	8.05	5.40	4.80	5.00	5.40	5.40
14	4.90	5.08	5.65	7.70	7.45	7.45	8.25	5.25	4.70	5.00	5.30	5.40
15	4.90	5.15	5.45	8.05	7.55	7.25	8.30	5.05	4.70	4.90	5.30	5.40
16	4.80	5.20	5.35	8.10	7.35	6.80	8.70	4.55	4.70	4.90	5.30	5.40
17	4.80	5.25	5.15	8.75	7.25	6.95	8.45	5.25	4.70	5.00	5.30	5.40
18	4.90	5.40	5.25	9.10	7.20	6.95	7.85	5.40	4.70	5.00	5.30	5.55
19	4.80	5.35	5.40	8.80	7.10	7.30	7.75	5.25	4.70	5.00	5.30	5.50
20	4.80	5.30	5.40	8.85	7.00	7.65	7.95	5.15	4.70	4.95	5.30	5.40
21	4.80	5.35	5.30	8.85	6.85	7.80	7.60	5.05	4.70	4.95	5.30	5.55
22	4.80	5.30	5.25	8.80	6.70	7.75	6.95	4.95	4.70	5.00	5.40	5.50
23	4.85	5.30	5.20	8.85	6.80	7.45	6.75	4.90	4.70	5.00	5.40	5.40
24	4.90	5.25	5.10	9.10	6.50	8.00	6.65	4.90	4.70	4.95	5.40	5.40
25	4.90	5.33	5.15	9.20	6.55	7.75	6.35	6.80	4.70	5.00	5.50	5.40
26	5.00	5.38	5.25	9.25	6.60	7.75	6.10	5.20	4.70	5.00	5.70	5.40
27	4.90	5.43	5.20	9.20	6.75	7.35	5.90	4.90	4.70	5.00	5.70	5.40
28	5.00	5.48	5.20	9.30	6.80	7.35	5.75	5.00	4.70	5.00	6.00	5.40
29	5.10	.....	5.10	9.20	6.95	6.95	5.45	4.90	4.60	5.00	6.00	5.40
30	5.20	.....	5.25	9.10	7.30	6.60	5.45	4.70	4.60	5.00	6.05	5.25
31	5.00	.....	5.30	.....	7.50	.....	5.35	4.65	.....	5.00	.....	5.20

Daily gage height, in feet, of Rio Grande at San Marcial, New Mexico, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Nov.	Dec.
1	7.70	7.80	7.80	7.40	9.85	8.20	8.50	6.65	4.40	.....	6.80
2	7.70	8.00	7.80	7.40	9.65	8.15	8.80	6.55	4.30	.....	7.00
3	7.60	7.90	7.90	7.40	9.45	8.50	8.80	6.40	4.00	.....	6.80
4	7.60	7.80	7.80	7.40	9.10	8.40	8.55	6.30	4.00	.....	6.55
5	7.60	7.70	7.80	7.40	8.90	8.40	8.35	6.20	3.80	3.35	6.50
6	7.60	7.70	7.80	7.40	8.80	8.25	8.40	6.00	3.80	3.80	6.60
7	7.70	7.70	7.80	7.60	8.70	8.65	8.35	6.00	3.80	4.00	6.50
8	7.70	7.70	7.70	7.60	8.60	8.50	7.95	6.60	3.80	4.20	6.40
9	7.70	7.80	7.70	7.60	8.60	8.30	7.75	6.00	3.80	4.55	6.30
10	7.70	7.80	7.70	7.70	8.60	8.80	8.25	7.50	5.40	4.85	6.30
11	7.70	7.90	7.80	8.10	8.70	8.60	7.65	7.75	7.55	5.05	6.20
12	7.70	7.90	7.80	8.25	8.60	8.75	7.60	6.90	5.60	5.40	6.30
13	7.70	7.90	7.80	8.35	8.55	8.85	7.40	6.35	4.90	5.70	6.50
14	7.70	7.80	7.80	8.60	8.55	8.70	9.30	6.00	4.65	5.80	6.50
15	7.70	7.80	7.90	8.60	8.65	8.65	8.65	5.85	4.30	5.90	6.50
16	7.70	7.70	7.90	8.80	8.80	8.60	10.40	5.70	4.00	6.00	6.50
17	7.70	7.70	7.80	9.00	8.75	8.45	10.75	5.50	3.80	6.20	6.50
18	7.70	7.60	7.70	9.30	8.60	8.20	10.25	5.50	3.80	6.40	6.70
19	7.70	7.60	7.70	9.60	8.50	8.40	8.35	6.00	3.60	6.20	6.75
20	7.70	7.70	7.70	9.90	8.50	8.30	7.95	6.30	3.60	6.20	7.00
21	7.70	7.70	7.70	9.80	8.40	8.20	7.80	6.10	3.60	6.30	7.60
22	7.70	7.60	7.70	9.50	8.20	8.60	7.70	5.75	3.60	6.40	7.25
23	7.70	7.80	7.70	9.20	8.00	8.50	7.65	5.50	3.60	6.50	6.75
24	7.60	7.90	7.60	9.70	8.00	8.60	7.60	5.25	3.60	6.30	6.50
25	7.50	7.80	7.60	9.70	7.90	8.50	7.50	5.00	.....	6.60	6.25
26	7.35	7.80	7.50	9.75	7.80	8.75	7.40	4.90	.....	6.50	6.00
27	6.80	7.80	7.50	9.65	7.70	8.75	7.30	4.80	.....	6.50	6.40
28	7.00	7.80	7.50	9.70	7.70	8.65	7.20	5.15	.....	6.55	6.40
29	7.45	.....	7.50	9.75	7.70	8.55	7.10	5.10	.....	6.50	6.50
30	7.70	.....	7.50	10.00	7.80	8.40	7.00	4.70	.....	6.60	6.70
31	7.80	.....	7.40	.....	7.90	.....	6.80	4.50	.....	.....	6.90

Sept. 5–9, water standing in pools. Sept. 10–16, water backed up. Sept. 19–24, standing in pools. Sept. 25–Nov. 4, dry.

Daily gage height, in feet, of Rio Grande at El Paso, Texas, for 1898.

Day.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	6.85	7.45	6.30	10.90	7.50	9.50	7.50	5.55	4.20	4.00	4.10
2	7.05	7.35	6.30	11.00	7.50	9.50	7.50	5.40	4.20	4.00	4.40
3	7.30	7.45	6.10	11.30	7.55	9.40	7.30	5.40	4.20	4.00	4.65
4	8.05	7.35	5.95	11.30	7.95	9.45	7.05	5.35	4.20	4.00	4.70
5	8.30	7.55	5.75	10.95	8.20	9.30	7.35	5.30	4.20	4.00	4.95
6	8.05	7.25	5.55	10.70	8.70	10.60	7.15	5.20	4.20	4.00	5.30
7	7.90	7.30	5.40	10.20	9.40	10.60	7.10	5.25	4.20	4.00	5.50
8	8.10	7.20	5.40	9.80	9.25	9.65	7.05	5.25	4.20	4.00	5.60
9	8.10	7.30	5.30	9.55	9.25	9.60	8.05	5.20	4.20	4.00	5.60
10	7.80	7.30	5.30	9.40	9.90	9.75	7.50	5.15	4.20	4.00	5.60
11	7.55	7.50	5.30	9.40	10.10	9.55	7.50	5.20	4.20	4.00	5.60
12	7.50	7.60	5.20	9.35	10.05	10.00	7.10	4.95	4.20	4.00	5.60
13	7.80	7.50	5.10	9.10	9.90	9.60	8.45	4.75	4.20	4.00	5.60
14	7.70	7.45	5.10	8.95	9.80	9.30	7.95	4.55	4.20	4.00	5.70
15	7.65	7.50	5.20	9.00	9.80	9.15	7.55	5.85	4.20	4.00	5.55
16	7.70	7.40	6.75	9.00	9.50	9.05	7.25	5.65	4.20	4.09	5.40
17	7.75	7.55	8.55	9.05	9.35	10.60	7.00	5.45	4.20	4.00	5.30
18	7.55	7.80	8.75	9.10	9.25	11.70	6.65	5.35	4.20	4.00	5.35
19	7.40	7.70	9.15	9.10	9.15	13.55	6.55	5.25	4.20	4.00	5.50
20	7.35	7.45	9.60	9.10	8.85	13.65	6.35	5.10	4.10	4.00	5.40
21	7.30	7.25	9.95	9.05	8.70	13.00	6.15	5.05	4.10	4.00	5.40
22	7.20	7.10	10.40	8.90	8.70	10.95	6.00	4.90	4.10	4.00	5.30
23	7.10	7.00	10.50	8.75	8.80	9.75	6.00	4.80	4.00	4.00	5.20
24	7.10	6.90	10.80	8.65	8.95	9.10	6.00	4.70	4.00	4.00	5.35
25	7.15	6.90	10.70	8.45	9.65	9.05	5.90	4.60	4.00	4.00	5.30
26	7.70	6.75	10.60	8.30	9.80	8.90	5.85	4.55	4.00	4.00	6.15
27	7.65	6.60	10.80	8.25	9.60	8.40	5.70	4.50	4.00	4.10	6.15
28	7.55	6.50	10.70	8.05	9.60	8.30	5.75	4.45	4.00	4.10	5.95
29	.....	6.40	10.70	7.80	9.65	7.95	6.15	4.40	4.00	4.10	5.85
30	.....	6.30	10.75	7.55	9.65	7.90	5.95	4.30	4.00	4.10	5.95
31	.....	6.30	.....	7.50	.....	7.80	5.75	.....	4.00	.....	6.00

List of discharge measurements.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
1896.				*Feet.*	*Sec.-feet.*
Dec. 30	Trinity River	Dallas, Tex	T. U. Taylor	55.80	48
Sept. 14	Brazos River	Waco, Tex	do	2.70	243
Dec. 26	do	do	do	2.50	142
Dec. 31	do	do	do	2.50	142
Feb. 22	do	Lewis, Tex	do	7.00	1,612
May 20	do	do	do	7.80	2,017
1897.					
Dec. 21	Colorado River	Austin, Tex	do	1.80	290
Dec. 22	do	do	do	1.95	355
Dec. 23	do	do	do	2.00	393
Dec. 24	do	do	do	2.05	408
Dec. 25	do	do	do	1.70	275
Dec. 28	do	do	do	1.70	278
1898.					
Jan. 5	do	do	do	.....	a 226
Jan. 6	do	do	do	.....	a 230
Jan. 7	do	do	do	.....	a 233
Jan. 13	do	do	do	.....	a 234
Jan. 22	do	do	do	1.80	297
Feb. 14	do	do	do	2.00	386
Do.	do	do	do	2.00	382
Feb. 17	do	do	do	2.71	1,080
Feb. 18	do	do	do	2.71	1,087
Feb. 19	do	do	do	2.52	876
Mar. 8	do	do	do	1.90	311
Apr. 28	do	do	do	2.38	581
Sept. 15	do	do	do	1.96	.....
Dec. 16	do	do	do	1.95	343
Dec. 21	do	do	do	.....	a 298
Dec. 22	do	do	do	.....	a 296
Mar. 12	Guadalupe River	New Braunfels, Tex.	do	2.00	350
Dec. 20	do	do	do	1.90	44
Apr. 14	Rio Grande	Del Norte, Colo	P. E. Harroun	3.27	1,966
May 18	do	do	do	3.23	1,802
June 23	do	do	do	5.25	5,181
Aug. 25	do	do	do	1.86	521
Oct. 28	do	do	do	1.48	244
Sept. 18	do	Embudo, N. Mex	do	7.70	271
Oct. 6	do	do	do	7.50	265
Oct. 28	do	do	do	7.00	284
May 19	do	Rio Grande, N. Mex.	do	7.00	2,671
Sept. 17	do	do	do	4.70	269
Oct. 7	do	do	do	4.60	258
Oct. 29	do	do	do	5.00	368
May 16	do	San Marcial, N. Mex.	do	8.80	2,943
Sept. 15	do	do	do	4.30	46

a Gaging made in tailrace at dam.

List of miscellaneous discharge measurements.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
1897.				*Feet.*	*Sec.-feet.*
Dec. 30	San Antonio River.	San Antonio, Tex..	T. U. Taylor.....	.....	11
1898.					
Jan. 1	Brazos River.....	Harlans Ford, Tex.	.....do.....	.....	132
Jan. 8	Colorado River	Sulphur Hollow, Tex.	.....do.....	.....	227
Jan. 12	Comal River	New Braunfels, Tex.	.....do.....	1.40	286
Jan. 14	San Felipe River...	Del Rio, Tex.....	.....do.....	.....	43
Do.	Madre Ditch	.....do.....	.....do.....	.....	25
Jan. 15	Devils River	Southern Pacific railroad bridge, Tex.	.....do.....	.....	362
Mar. 17	San Antonio River.	Hot Wells, Tex....	.....do.....	.....	9
Mar. 18	Comal River	New Braunfels, Tex.	.....do.....	1.40	312
Mar. 19	San Marcos River..	San Marcos, Tex...	.....do.....	.....	51
Mar. 26	Barton Spring	Austin, Tex.....	.....do.....	.....	20
May 3	.....do.....	.....do.....	.....do.....	.....	30
Do.	.....do.....	.....do.....	.....do.....	.....	31
Sept. 5	Pecos River.....	Flume 6 miles above Pecos, Tex.	.....do.....	2.00	80
Do.	Margueretta Flume	6 miles above Pecos, Tex.	.....do.....	1.80	114
Sept. 6	Arroya Flume	Below Lake Avalon, Tex.	.....do.....	.....	321
Sept. 7	Pecos River.....	Eddy, N. Mex	.....do.....	.....	157
Sept. 8	Delaware River....	Crossing of Pecos Valley Railroad.	.....do.....	.....	4
Do.	Pecos River	Redbluff, N. Mex..	.....do.....	.....	227
Sept. 12	Brazos River.....	Brazos, Tex.....	.....do.....	3.25	80
Sept. 13	Trinity River.....	Fort Worth, Tex ..	.....do.....	.....	11
Sept. 16	San Marcos River..	Westfield, Tex	.....do.....	.....	86
Dec. 23	Barton Spring.....	Austin, Tex	.....do.....	.....	19
Dec. 24	.....do.....	.....do.....	.....do.....	.....	19

Rating tables.

Del Norte.		Embudo.		Rio Grande.		San Marcial.	
Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Sec.-feet.*	*Feet.*	*Sec.-feet.*	*Feet.*	*Sec.-feet.*	*Feet.*	*Sec.-feet.*
1.4	194	7.5	285	4.3	230	5.0	5
1.5	260	7.6	285	4.4	240	5.2	21
1.6	328	7.7	310	4.5	250	5.4	37
1.7	398	7.8	345	4.6	260	5.6	53
1.8	468	7.9	385	4.7	270	5.8	69
1.9	540	8.0	425	4.8	290	6.0	85
2.0	614	8.2	515	4.9	320	6.2	101
2.1	692	8.4	605	5.0	360	6.4	120
2.2	772	8.6	725	5.2	450	6.6	170
2.3	856	8.8	875	5.4	560	6.8	270
2.4	942	9.0	1,025	5.6	710	7.0	400
2.5	1,032	9.2	1,175	5.8	880	7.2	580
2.6	1,128	9.4	1,360	6.0	1,090	7.4	850
2.7	1,228	9.6	1,570	6.2	1,330	7.6	1,200
2.8	1,333	9.8	1,790	6.4	1,590	7.8	1,650
2.9	1,442	10.0	2,010	6.6	1,910	8.0	2,150
3.0	1,556	10.2	2,260	6.8	2,250	8.2	2,800
3.2	1,811	10.4	2,540	7.0	2,670	8.4	3,600
3.4	2,120	10.6	2,820	7.2	3,110	8.6	4,450
3.6	2,440	10.8	3,105	7.4	3,550	8.8	5,350
3.8	2,760	11.0	3,395	7.6	3,990	9.0	6,250
4.0	3,080	11.2	3,685	7.8	4,450	9.2	7,150
4.2	3,406	11.4	3,975	8.0	4,910	9.4	8,050
4.4	3,737	11.6	4,265	8.2	5,380	9.6	8,925
4.6	4,076	11.8	4,555	8.4	5,860	9.8	9,850
4.8	4,416	12.0	4,845	8.6	6,340	10.0	10,750
5.0	4,756	.....	.....	8.8	6,820	10.2	11,650
5.2	5,096	.....	.....	9.0	7,300	10.4	12,550
5.4	5,436	.....	.....	9.2	7,780	.....	.....
.....	.....	.....	.....	9.4	8,260	.....	.....

COLORADO RIVER DRAINAGE.

DESCRIPTION OF RIVER STATIONS.

Granger station on Black Fork.—Described on page 134 of Paper No. 16; results for 1897 given on pages 391–393 of the Nineteenth Annual Report, Part IV.

Greenriver station on Green River.—Described on page 135 of Paper No. 16; results for 1897 shown on pages 394–396 of the Nineteenth Annual Report, Part IV.

Blake station on Green River.—Described on page 136 of Paper No. 16; results for 1897 given on pages 396–398 of the Nineteenth Annual Report, Part IV.

Grand Junction station on Grand River.—Described on page 137 of Paper No. 16; results for 1897 given on pages 399–401 of the Nineteenth Annual Report, Part IV.

Fort Crawford station on Uncompahgre River.—Described on page 139 of Paper No. 16; results for 1897 given on pages 402–404 of the Nineteenth Annual Report, Part IV.

Grand Junction station on Gunnison River.—Described on page 141 of Paper No. 16; results for 1897 given on pages 404–406 of the Nineteenth Annual Report, Part IV.

Fallcreek station on San Miguel River.—Described on page 142 of Paper No. 16; results for 1897 given on pages 406–407 of the Nineteenth Annual Report, Part IV.

Mancos station on Mancos River.—This station is located at about the center of the town of Mancos, Colorado, 100 feet below a wagon bridge across the river, and was established April 9, 1898. The gage consists of a vertical 2 by 4 inch by 12 foot timber, marked in tenths, securely wired and spiked to a cottonwood tree on left bank of river. Measurements are usually made by wading, but the wagon bridge may be used at high water, the initial point being on the left side. The banks are not liable to overflow. The channel is in gravel but is not liable to much change. The channel is straight for 100 feet above and 300 feet below. The location of the station is such that the discharge is practically the amount lost to irrigation, most of the ditches being taken out above. The observer is Mrs. K. D. Kelley, who lives about 200 feet from the gage.

Dolores station on Dolores River.—Described on page 143 of Paper No. 16; results for 1897 given on pages 407–409 of the Nineteenth Annual Report, Part IV.

Arboles station on San Juan River.—Described on page 144 of Paper No. 16; results for 1897 given on pages 409–410 of the Nineteenth Annual Report, Part IV. The footbridge was washed out in August. The observer is J. D. Lister.

Arboles station on Piedra River.—Described on page 145 of Paper No. 16; results for 1897 given on pages 411–413 of the Nineteenth Annual Report, Part IV. The observer is J. D. Lister.

Durango station on Animas River.—Described on page 146 of Paper No. 16; results for 1897 given on pages 414–415 of the Nineteenth Annual Report, Part IV.

Queen Creek station on Queen Creek.—Described on page 417 of Nineteenth Annual Report, Part IV. Observations were not begun until July 1, 1898. It is reported that there was water in the creek earlier in the year, probably in January or February, but the quantity was not notably large. From that time the bed was dry until August 8, and again dry from September 2 to December 17; on December 18 a discharge of 20 second-feet was reported, and the creek was again dry from December 19 to 31. From July 1 to September 10 the observer was John Green. His record is given below showing date, height of water, and area of cross section computed by Mr. Cyrus C. Babb, by using the cross section made by Mr. Albert T. Colton on July 15, 1898.

Height of water and area of cross section of Queen Creek.

Date.	Gage height.	Area.
	Feet.	*Sq. feet.*
August 8, night	4.5	121
August 18, afternoon	24.2	100
August 22, afternoon	5.2	220
August 23, afternoon	4.4	113
August 27, afternoon	5.4	200
August 29, 7.30 p. m.	7.0	605
August 30, 5 a. m	(*a*)	(*a*)
August 31, 2 p. m	9.0	691
September 1, 7 a. m	(*b*)	(*b*)
September 1, 2 p. m	4.0	111

a No flow. *b* Rising.

The flood of August 31 modified the channel of the creek to a considerable extent. The area of cross section since that time has been computed from measurements made December 27, 1898. On November 16 Mr. Babb extended the rod, lowering the zero by 3 feet and changing the records made before that time to accord with the new datum. On the same day a sloping rod referred to the same datum was placed 431 feet upstream from the main gage. The creek was dry from September 10 until December 16. The observer, W. E. Holman, reported that water appeared at Hewitt's ranch on the morning of December 17, the quantity being about 10 second-feet and somewhat more at night. This water reached a tank 400 feet above the upper rod or approximately 2 miles below Hewitt's at 3 p. m. December 17; on December 18, at 9 a. m., and again at 4 p. m. the lower gage read 2.0 feet and the upper gage 6.0 feet; the creek was then 25 feet wide and the discharge about 20 second-feet. On December 18 the creek at the gages was again dry. For several days thereafter there was a slight flow at Hewitt's, but this did not reach the gages, being absorbed in the sandy channel. From the facts available Mr. Babb has roughly estimated that the discharge for the creek for the year 1898 was 5,000

acre-feet, not taking into account the quantity which may have flowed during the early part of the year.

Buttes station on the Gila River.—Described on page 147 of Paper No. 16; results for 1897 given on pages 415–417 of the Nineteenth Annual Report, Part IV. The bench mark described in the Annual Report for 1897, consisting of an X chiseled in the face of the rock, has been destroyed and a new one established. This is on a ledge of rock 69.4 feet east of south cable anchor and 4.4 feet above ground. Its elevation is 1,608.45 feet above sea level. The zero of the gage is 1,583 feet or 25.45 feet below this bench mark. Occasional measurements, as shown on page 142, have been made, but systematic observations could not be had until November 25, 1898. Since that date computations of daily discharge have been made.

McDowell station on Salt River.—Described on page 148 of Paper No. 16; results for 1897 given on pages 418–420 of the Nineteenth Annual Report, Part IV.

McDowell station on Verde River.—Described on page 150 of Paper No. 16; results for 1897 given on pages 420–423 of the Nineteenth Annual Report, Part IV. No constant relation between gage height and discharge being discoverable, no rating table was constructed, the daily mean discharges being obtained by approximation.

Yuma station on Colorado River.—Described on page 151 of Paper No. 16.

TABLES OF DAILY GAGE HEIGHT.

Daily gage height, in feet, of Black Fork at Granger, Wyoming, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Oct.	Nov.	Dec.
1	1.10	.....	.....	2.35	2.80	2.80	1.65	0.20	.....	0.20	.....
2	.....	.....	.....	2.50	2.65	2.85	1.55	.15	0.00	.20	.....
3	.....	.....	.....	3.10	2.50	3.00	1.40	.10	.00	.10	.....
4	.....	.....	.....	2.80	2.25	2.85	1.30	.10	.00	.10	.....
5	.....	1.00	2.60	2.10	2.20	2.75	1.25	.10	.00	.10	.....
6	.....	.....	.....	1.90	2.15	2.65	1.20	.10	.05	.00	0.50
7	1.10	.....	.....	2.00	2.20	2.60	1.10	.10	.10	.00	.....
8	.....	.....	.....	2.00	2.25	2.35	1.10	.10	.10	.00	.....
9	.....	.....	.....	2.50	2.35	2.40	1.10	.10	.10	.00	.....
10	.....	.....	.....	2.95	2.20	2.35	1.10	.10	.10	.00	.....
11	.....	.....	.....	2.70	2.25	2.40	1.10	.10	.10	.00	.....
12	.....	1.00	2.00	2.80	2.45	2.45	1.10	.10	.20	.20	.....
13	.....	.....	.....	2.65	2.65	2.50	1.10	.00	.20	.00	.....
14	.....	.....	.....	2.50	3.00	2.80	1.10	.00	.20	.00	.....
15	1.10	.....	.....	2.50	3.05	3.05	1.00	.00	.20	.00	.50
16	.....	.....	.....	2.70	2.95	2.90	.90	.00	.20	.00	.....
17	.....	.....	.....	2.80	2.95	2.95	.80	.00	.20	.00	.....
18	.....	.....	.....	2.95	3.40	3.35	.70	.25	.40	.00	.....
19	.....	2.60	1.90	3.00	3.05	3.25	.60	.50	.80	.20	.....
20	.....	.....	.....	2.70	3.00	2.95	.50	.40	.30	.00	.....
21	.....	.....	.....	2.60	2.65	2.90	.50	.30	.20	.00	.....
22	1.10	.....	.....	2.95	2.40	2.95	.50	.20	.20	.00	.....
23	.....	.....	.....	2.90	2.25	2.75	.50	.10	.20	.00	.50
24	.....	.....	.....	2.50	2.65	3.10	.45	.10	.20	.00	.....
25	.....	.....	.....	2.35	2.90	3.10	.40	.00	.20	.00	.....
26	.....	1.90	1.60	2.35	3.00	2.60	.40	.00	.20	.50	.....
27	.....	.....	.....	2.80	3.00	2.20	.40	.00	.20	.....	.....
28	.....	.....	.....	3.15	2.95	2.05	.30	.00	.20	.....	.....
29	1.10	.....	.....	3.10	3.00	2.00	.30	.00	.20	.....	.....
30	.....	.....	.....	3.00	2.95	1.90	.20	.00	.20	.....	.....
31	.....	.....	2.10	.....	2.75	.....	.20	(a)	.20	.....	.50

a August 31 to October 2, water standing in pools.

Daily gage height, in feet, of Green River at Greenriver, Wyoming, for 1898.

Day.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	1.20	2.60	3.65	4.00	2.00	1.45	0.78	0.80	.....
2	1.25	2.58	3.48	3.85	1.95	1.40	.80	.....	.....
3	1.35	3.53	3.28	3.68	1.93	1.43	.85	.80	.....
4	1.47	2.50	3.30	3.50	1.83	1.45	.85	.....	.....
5	1.53	2.45	3.40	3.43	1.75	1.40	.90	.80	.....
6	1.43	2.40	3.33	3.38	1.75	1.38	.90	.80	.....
7	1.27	2.33	3.23	3.33	1.78	1.33	.85	.80	.....
8	1.45	2.28	3.13	3.28	1.78	1.25	.85	.80	.....
9	1.45	2.13	3.03	3.13	1.75	1.23	.85	.80	.....
10	1.55	2.23	2.95	3.10	1.70	1.18	.90	.70	1.00
11	1.60	2.28	3.00	3.10	1.65	1.15	.90	.75	.....
12	2.10	2.35	3.08	3.13	1.62	1.10	.90	1.50	.....
13	2.98	2.43	3.20	3.20	1.58	1.10	.90	1.40	.....
14	3.13	2.68	3.50	3.25	1.55	1.05	.90	1.20	.....
15	2.95	2.85	3.85	3.23	1.60	1.05	.90	1.00	1.10
16	2.83	2.93	4.05	3.15	1.65	1.08	.90	.90	1.10
17	3.00	2.95	4.23	3.10	1.65	1.00	.85	.60	.....
18	3.23	2.95	4.33	3.05	1.60	1.00	.85	.80	.....
19	3.08	3.03	4.45	2.98	1.55	.95	.85	.90	1.20
20	2.73	3.00	4.63	2.88	1.55	.95	.85	.90	.....
21	2.55	2.98	4.68	2.65	1.55	.90	.85	.90	.....
22	2.48	2.78	4.75	2.45	1.50	.90	.85	.85	.....
23	2.35	2.60	4.83	2.33	1.48	.85	.80	.80	1.30
24	2.45	2.65	4.90	2.30	1.38	.83	.80	.80	.....
25	2.35	2.85	4.98	2.30	1.38	.80	.80	.80	.....
26	2.35	3.43	5.15	2.25	1.25	.80	.80	.85	1.40
27	2.38	3.50	5.23	2.23	1.20	.80	.80	.....	.....
28	2.48	3.50	4.88	2.20	1.15	.80	.80	.....	.....
29	2.60	3.58	4.53	2.15	1.13	.75	.80	.....	.....
30	2.63	3.70	4.25	2.08	1.28	.75	.80	.....	.....
31	.....	3.65	.....	2.03	1.45	.....	.80	.....	1.50

Daily gage height, in feet, of Green River at Blake, Utah, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	1.35	4.10	4.00	3.20	6.30	6.65	7.05	2.95	2.15	1.50	2.00	1.40
2	1.40	4.00	4.10	3.10	6.30	6.70	6.90	2.90	2.25	1.60	2.10	1.50
3	1.50	3.90	4.15	3.00	6.20	6.85	6.75	2.80	2.25	1.60	2.00	1.30
4	1.75	4.00	4.25	3.00	6.30	7.00	6.55	2.70	2.40	1.60	2.20	1.40
5	1.95	4.10	4.30	2.95	6.20	6.90	6.20	2.65	2.70	1.70	2.10	1.50
6	2.40	4.00	4.20	2.90	6.30	6.80	5.80	2.55	2.60	1.70	2.00	1.60
7	2.70	4.00	4.10	3.00	6.30	6.70	5.40	2.50	2.30	1.70	2.10	1.60
8	3.00	4.10	4.05	3.10	6.60	6.65	5.15	2.50	2.30	1.70	2.00	1.60
9	3.25	3.90	3.95	3.20	6.30	6.60	5.05	2.40	2.25	1.70	2.10	1.60
10	3.45	4.00	3.85	3.30	6.30	6.40	5.00	2.40	2.25	1.80	2.00	1.60
11	3.70	3.95	3.65	3.45	6.30	6.30	5.20	2.40	2.40	1.80	2.10	1.60
12	3.80	3.75	3.45	3.70	6.30	6.35	5.10	2.40	2.30	1.80	2.10	1.60
13	4.00	3.65	3.25	4.10	6.10	6.45	5.00	2.40	2.20	1.90	2.10	1.60
14	3.90	3.55	3.20	4.45	6.30	6.55	5.10	2.40	2.20	1.90	2.05	1.60
15	4.00	3.60	3.20	4.60	6.30	6.65	5.00	2.40	2.10	1.90	1.30	1.60
16	4.10	3.70	3.15	4.90	6.40	6.75	4.90	2.40	2.10	1.90	1.30	1.60
17	3.95	3.80	3.10	5.25	6.50	6.80	5.00	2.40	2.00	1.90	1.40	1.60
18	3.95	3.60	3.05	5.45	6.40	6.90	4.85	2.40	2.00	1.90	1.30	1.60
19	4.10	3.70	3.00	5.65	6.30	6.95	4.55	2.40	2.00	1.90	1.20	1.70
20	4.00	3.70	3.00	5.85	6.30	7.00	4.40	2.50	2.00	1.90	1.30	1.70
21	3.90	3.70	3.00	6.05	6.20	7.10	4.30	2.40	1.90	1.90	1.20	1.70
22	4.00	3.80	3.00	6.20	6.30	7.20	4.20	2.40	1.90	2.00	1.20	1.70
23	4.05	3.80	3.00	6.30	6.40	7.35	4.10	2.40	1.85	2.00	1.20	1.70
24	4.00	3.90	3.00	6.25	6.35	7.60	4.00	2.40	1.80	2.00	1.30	1.70
25	4.10	3.90	3.00	6.15	6.35	7.90	3.90	2.40	1.75	2.00	1.30	1.70
26	3.95	3.90	3.00	6.05	6.40	7.75	3.80	2.40	1.70	2.00	1.30	1.70
27	3.95	3.90	3.05	5.90	6.30	7.55	3.70	2.35	1.55	2.00	1.30	1.70
28	4.10	4.00	3.35	6.00	6.40	7.50	3.50	2.30	1.40	2.00	1.40	1.70
29	3.95	.....	3.50	6.10	6.40	7.40	3.25	2.30	1.40	2.00	1.50	1.70
30	4.00	.....	3.40	6.20	6.45	7.30	3.15	2.30	1.45	2.00	1.50	1.80
31	4.00	.....	3.30	.....	6.55	.....	3.05	2.20	.....	2.00	.....	1.80

Daily gage height, in feet, of Grand River, left channel, rod No. 2, at Grand Junction, Colorado, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	4.00				6.05	7.70	6.45	3.60	3.20	3.00	3.30	3.40
2				3.60	5.80	7.90	6.40	3.50	3.30	3.00	3.30	3.40
3					5.45	8.30	6.25	3.50	3.30	3.00	3.30	3.30
4					5.30	8.60	6.00	3.40	3.30	3.00	3.30	
5	4.40		3.90		5.30	8.35	5.75	3.30	3.30	3.00	3.30	
6					5.30	7.95	5.60	3.30	3.30	3.00	3.30	
7					5.20	7.80	5.50	3.30	3.30	3.00	3.30	3.10
8	4.70				5.20	7.99	5.40	3.30	3.25	3.00	3.30	
9				4.10	5.20	7.85	5.40	3.30	3.20	3.00	3.30	
10					5.10	7.60	5.40	3.40	3.20	3.10	3.30	2.90
11					5.25	7.70	5.30	3.35	3.20	3.20	3.20	
12	4.10		3.80		5.65	7.85	5.30	3.30	3.20	3.20	3.20	
13					5 85	7.75	5.45	3.30	3.20	3.20	3.20	3.00
14					6.25	7.75	5.75	3.30	3 20	3.15	3.10	
15	4.20				6.45	7.85	5.60	3.30	3.20	3.10	3.10	
16				4.60	6.35	8.15	5.35	3.20	3.20	3.20	3.10	
17					6.30	8.40	5.15	3.20	3.20	3.30	3.10	3.00
18					6.20	8.50	4.95	3.20	3.20	3.30	3.20	
19	4.10	4.50	3.70		6.20	8.60	4.80	3.20	3.15	3.30	3.20	
20					6.20	8.45	4.65	3.20	3.10	3.30	3.20	
21					6.05	8.35	4.45	3.20	3.10	3.30	3.30	3.10
22	4.10				5.90	8.10	4.40	3.20	3.10	3.30	3.40	
23				5.10	5.85	8.15	4.20	3.20	3.10	3.30	3.40	
24					6.20	8.15	4.15	3.20	3.10	3.30	3.30	3.20
25				5.10	6.55	7.90	4.05	3.30	3.10	3.30	3.30	
26	4.00	3.80	3.80		7.05	7.65	4.00	3.40	3.10	3.30	3.30	
27					7.20	7.40	4.00	3.30	3.10	3.30	3.30	3.10
28					7.40	7.10	3.85	3.20	3.10	3.30	3.30	
29					7.70	6.85	3.80	3.20	3.05	3.30	3.30	
30				6.20	7.70	6.65	3.70	3.20	3.00	3.30	3.40	
31					7.60		3.60	3.20		3.30		4.00

Daily gage height, in feet, of Grand River, right channel, rod No. 1, at Grand Junction, Colorado, for 1898.

Day.	May.	June.	July.	Day.	May.	June.	July.	Day.	May.	June.	July.
1		0.70	0.00	12		0.85		23	0.00	1.15	
2		.90	.00	13		.75		24	.00	1.15	
3		1.30		14		.75		25	.00	.90	
4		1.60		15		.85		26	.10	.65	
5		1.35		16		1.15		27	.20	.30	
6		.95		17		1.40		28	.40	.00	
7		.80		18		1.50		29	.70	.00	
8		.90		19		1.60		30	.70	.00	
9		.85		20		1.45		31	.60	.00	
10		.60		21		1.35					
11		.70		22	0.00	1.15					

Daily gage height, in feet, of Uncompahgre River at Fort Crawford, Colorado, for 1898.

Day.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.
1	.....	4.60	4.75	4.95	3.75	3.80	3.70	3.75
2	.....	4.60	5.00	4.95	3.65	3.85	3.70	3.75
3	.....	4.15	5.00	4.95	3.50	3.90	3.70	3.75
4	.....	4.20	4.95	4.85	3.70	3.90	3.70	3.70
5	.....	4.15	4.85	4.90	3.70	3.90	3.70	3.80
6	.....	4.10	4.95	4.95	3.70	3.80	3.70	3.75
7	.....	4.10	5.25	4.95	3.70	3.85	3.70	3.70
8	.....	4.00	5.05	4.85	3.70	3.75	3.70	3.75
9	.....	3.95	5.00	4.85	3.70	3.75	3.70	3.75
10	3.60	3.95	4.95	4.80	3.70	3.65	3.70	3.85
11	3.70	3.90	4.95	4.55	3.70	3.65	3.70	3.70
12	3.35	4.00	4.80	4.95	3.70	3.80	3.70	3.65
13	3.80	3.90	4.55	5.05	3.70	3.85	3.70	3.65
14	4.35	4.05	4.95	5.05	3.70	3.85	3.70	3.65
15	4.40	4.05	5.05	5.55	3.70	3.85	3.70	3.60
16	4.40	4.05	5.05	5.45	3.90	3.85	3.70	3.65
17	4.40	4.00	5.55	4.80	4.05	3.85	3.75	3.65
18	4.25	4.05	5.45	4.55	4.00	3.75	3.80	3.65
19	4.15	4.05	5.45	4.35	4.00	3.70	3.75	3.65
20	4.40	4.05	5.45	4.35	4.10	3.70	3.75	3.65
21	4.35	4.00	5.60	4.35	4.15	3.70	3.80	3.70
22	4.35	4.05	5.55	4.20	4.10	3.70	3.70	3.75
23	4.25	4.30	5.65	4.25	4.00	3.70	3.75	3.70
24	4.15	4.40	5.75	4.05	4.15	3.70	3.75	3.65
25	4.40	4.35	5.70	4.05	4.15	3.70	3.75	3.80
26	4.60	4.45	5.45	3.85	4.25	3.70	3.75	3.90
27	4.65	4.45	4.60	3.95	4.25	3.70	3.85	3.85
28	4.60	4.50	5.00	3.95	4.00	3.70	3.85	3.80
29	4.65	4.60	5.05	3.80	3.90	3.70	3.85	3.70
30	4.45	4.75	5.05	3.85	3.75	3.70	3.80	3.75
31	.....	4.65	.....	3.65	3.65	.....	3.85	.....

Approximated from August 4 to August 14 and from September 21 to October 8, inclusive.

Daily gage height, in feet, of Gunnison River at Grand Junction, Colorado, for 1898.

Day.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.
1	4.80	5.40	4.10	1.90	1.50	1.30	1.60
2	4.60	5.40	4.10	1.80	1.50	1.30	1.60
3	4.40	5.80	4.00	1.80	1.50	1.30	1.60
4	4.30	5.90	3.70	1.70	1.50	1.30	1.60
5	4.20	5.70	3.50	1.60	1.50	1.30	1.60
6	4.20	5.40	3.40	1.60	1.50	1.30	1.60
7	4.10	5.40	3.60	1.60	1.50	1.30	1.60
8	4.20	5.50	3.80	1.60	1.40	1.30	1.60
9	4.20	5.50	3.70	1.80	1.40	1.30	1.60
10	4.20	5.30	3.70	1.70	1.40	1.30	1.60
11	4.20	5.20	3.60	1.70	1.40	1.40	1.50
12	4.40	5.20	3.50	1.70	1.40	1.40	1.30
13	4.60	5.20	3.50	1.70	1.40	1.40	1.30
14	4.70	5.30	3.50	1.60	1.40	1.40	1.20
15	4.90	5.30	3.40	1.60	1.40	1.40	1.20
16	4.70	5.30	3.20	1.60	1.40	1.40	1.20
17	4.50	5.60	3.20	1.50	1.40	1.40	1.20
18	4.40	5.80	3.20	1.50	1.40	1.50	1.20
19	4.30	5.90	3.10	1.50	1.40	1.50	1.20
20	4.40	5.70	2.90	1.50	1.40	1.50	1.30
21	4.50	5.70	2.80	1.60	1.30	1.60	1.40
22	4.30	5.50	2.70	1.60	1.30	1.60	1.40
23	4.30	5.40	2.60	1.60	1.30	1.60	1.30
24	4.60	5.60	2.60	1.50	1.30	1.60	1.30
25	4.70	5.50	2.50	1.50	1.30	1.60	1.30
26	4.80	5.20	2.50	1.60	1.30	1.60	1.30
27	4.80	5.00	2.40	1.60	1.30	1.60	1.30
28	5.00	4.60	2.30	1.60	1.30	1.60	1.40
29	5.10	4.20	2.20	1.50	1.30	1.60	1.40
30	5.20	4.20	2.10	1.50	1.30	1.60	1.50
31	5.40	.....	2.00	1.50	.....	1.60	.....

Daily gage height, in feet, of San Miguel River at Fallcreek, Colorado, for 1898.

Day.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.
1	.....	3.30	4.15	4.25	2.75	2.70	2.50	2.30
2	.....	3.10	4.25	4.00	2.70	2.70	2.50	2.35
3	.....	3.10	4.20	3.95	2.70	2.70	2.40	2.35
4	.....	3.20	4.25	3.90	2.75	2.70	2.40	2.35
5	.....	3.15	4.15	4.30	2.85	2.70	2.40	2.35
6	.....	3.15	4.20	4.25	2.90	2.70	2.50	2.30
7	.....	3.05	4.40	4.00	3.00	2.75	2.45	2.30
8	.....	3.20	4.40	4.05	3.00	2.70	2.45	2.30
9	.....	3.20	4.15	3.95	2.90	2.70	2.50	2.30
10	.....	3.20	4.10	3.90	2.90	2.70	2.50	2.30
11	3.10	3.30	4.05	3.80	2.90	2.70	2.40	2.40
12	3.25	3.35	4.00	3.85	2.80	2.65	2.40	2.40
13	3.25	3.45	4.05	3.80	2.90	2.60	2.40	2.40
14	3.30	3.45	4.00	3.75	2.90	2.60	2.40	2.40
15	3.30	3.40	4.30	3.70	2.90	2.55	2.40	2.35
16	3.25	3.40	4.55	3.60	2.80	2.55	2.40	2.40
17	3.25	3.30	4.70	3.55	2.80	2.55	2.40	2.30
18	3.05	3.30	4.55	3.35	2.75	2.55	2.40	2.30
19	3.05	3.30	4.65	3.30	2.70	2.55	2.40	2.30
20	3.15	3.20	4.55	3.20	2.75	2.50	2.40	2.30
21	3.20	3.20	4.60	3.20	2.70	2.50	2.40	2.25
22	3.05	3.25	4.85	3.05	2.75	2.55	2.40	2.25
23	3.15	3.45	5.05	3.00	2.80	2.60	2.40	2.30
24	3.20	3.40	4.55	3.00	2.80	2.60	2.40	2.30
25	3.35	3.50	4.55	3.00	2.75	2.55	2.40	2.40
26	3.55	3.40	4.50	3.00	2.70	2.60	2.40	2.40
27	3.75	3.50	4.35	2.90	2.70	2.50	2.40	2.50
28	3.60	3.60	4.30	2.85	2.70	2.50	2.40	2.50
29	3.60	3.80	4.25	2.80	2.70	2.50	2.35	2.50
30	3.40	3.95	4.20	2.80	2.80	2.50	2.35	2.50
31	.....	3.90	.....	2.70	2.70	.....	2.30	.....

Daily gage height, in feet, of Mancos River at Mancos, Colorado, for 1898.

Day.	Apr.	May.	June	July.	Aug.	Sept.	Day.	Apr.	May.	June	July.	Aug.	Sept.
1	.....	2.50	2.45	1.80	1.20	1.20	17	2.70	2.05	2.15	1.90	1.10	1.00
2	.....	2.50	2.45	1.70	1.10	1.10	18	2.70	2.00	2.40	1.70	1.10	1.10
3	.....	2.40	2.50	1.60	1.10	1.10	19	2.70	2.10	2.15	1.60	1.10	1.10
4	.....	2.40	2.35	2.60	1.10	1.10	20	2.55	2.40	2.40	1.60	1.10	1.10
5	.....	2.60	2.40	2.70	1.20	1.10	21	2.55	2.00	2.40	1.60	1.10	1.10
6	.....	2.50	2.40	2.90	1.20	1.10	22	2.50	2.00	2.40	1.60	1.10	1.10
7	.....	2.30	2.35	2.50	1.10	1.10	23	2.40	2.30	2.40	1.60	1.10	1.10
8	.....	2.30	2.30	2.10	1.10	1.10	24	2.60	2.00	2.70	1.40	1.15	1.10
9	.....	2.20	2.30	2.10	1.10	1.00	25	2.70	2.10	2.40	1.20	1.20	.90
10	1.90	2.20	2.25	2.20	1.10	1.00	26	2.70	2.30	2.40	.80	1.20	.90
11	2.00	2.20	2.20	2.10	1.10	1.00	27	2.70	2.30	2.40	.80	1.20	.90
12	2.00	2.30	2.25	2.00	1.10	1.00	28	2.50	2.30	2.30	.70	1.10	.90
13	2.40	2.30	2.20	1.90	1.10	1.00	29	2.75	2.30	2.20	.70	1.10	.80
14	3.10	3.30	2.20	1.80	1.10	1.00	30	2.80	2.50	2.00	.70	1.10	.80
15	2.80	2.30	2.20	1.80	1.10	1.00	31	.....	2.50	.....	1.20	1.20	.....
16	2.70	2.20	2.15	1.90	1.10	1.00							

Daily gage height, in feet, of Gila River at Buttes, Arizona, for 1898.

Day.	Nov.	Dec.	Day.	Nov.	Dec.	Day.	Nov.	Dec.	Day.	Nov.	Dec.
1	.....	2.35	9	.....	2.50	17	.....	2.80	25	2.10	.....
2	.....	2.35	10	.....	.....	18	.....	2.85	26	2.20	2.80
3	.....	2.35	11	.....	2.60	19	.....	2.90	27	2.20	2.80
4	.....	2.40	12	.....	2.75	20	.....	2.90	28	2.10	2.85
5	.....	2.40	13	.....	2.50	21	.....	2.90	29	2.25	2.75
6	.....	2.40	14	.....	2.70	22	.....	2.90	30	2.30	2.80
7	.....	2.45	15	.....	2.75	23	.....	2.90	31	.....	2.80
8	.....	2.45	16	.....	2.75	24	.....	2 95			

Daily gage height, in feet, of Salt River at McDowell, Arizona, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	10.10	11.20	11.80	10.80	11.30	10.20	9.90	11.50	12.00	10.35	10.45	10.60
2	10.10	11.00	11.40	10.80	11.30	10.20	9.90	11.30	12.50	10.35	10.45	10.60
3	10.10	10.90	11.50	10.80	11.20	10.20	9.85	10.95	11.90	10.35	10.45	10.60
4	10.10	10.90	11.50	10.80	11.15	10.15	9.85	10.90	11.50	10.35	10.45	10.60
5	10.10	10.95	11.50	10.90	11.10	10.10	9.95	10.90	11.40	10.35	10.45	10.60
6	10.10	10.95	11.35	11.00	11.05	10.10	11.00	10.90	11.50	10.35	10.50	10.60
7	10.10	10.90	11.30	11.00	11.00	10.10	10.60	10.95	11.10	10.35	10.50	10.60
8	10.10	11.00	11.30	11.00	11.00	10.10	11.00	10.90	11.00	10.35	10.50	10.60
9	10.10	11.10	11.30	11.05	10.95	10.05	10.90	10.90	11.00	10.35	10.50	10.65
10	10.15	11.30	11.30	11.40	10.90	10.05	10.40	10.90	10.95	10.35	10.50	10.65
11	10.30	11.35	11.40	11.40	10.80	10.10	10.35	10.90	10.80	10.35	10.50	10.90
12	10.40	11.00	11.70	11.70	10.70	10.05	10.60	10.80	11.10	10.40	10.45	10.80
13	10.40	10.90	11.60	11.80	10.65	10.05	10.90	10.80	11.00	10.40	10.45	10.85
14	10.30	10.80	11.60	11.70	10.60	10.05	11.00	10.80	10.95	10.35	10.50	10.90
15	10.20	10.70	11.50	11.60	10.50	10.10	11.30	10.75	10.85	10.40	10.50	10.80
16	10.20	10.70	11.50	11.60	10.50	10.10	11.75	10.85	10.85	10.35	10.50	10.80
17	10.20	10.75	11.40	11.75	10.50	10.05	11.75	10.70	10.80	10.35	10.50	11.00
18	10.20	10.80	11.30	12.00	10.45	10.05	12.20	10.80	10.70	10.35	10.50	11.00
19	10.20	10.90	11.30	12.10	10.50	10.00	11.50	10.90	10.60	10.35	10.50	11.10
20	10.20	10.90	11.20	12.20	10.50	10.00	12.30	10.80	10.55	10.40	10.50	11.10
21	10.15	11.00	11.20	12.25	10.40	10.00	12.10	10.80	10.55	10.40	10.50	11.05
22	10.15	11.00	11.15	12.10	10.40	10.00	11.80	10.80	10.50	10.40	10.55	11.00
23	10.15	11.00	11.10	12.00	10.40	10.40	11.50	10.80	10.60	10.40	10.55	10.90
24	10.15	10.95	11.00	11.90	10.30	10.30	12.00	10.30	10.60	10.40	10.55	10.90
25	10.15	10.95	11.00	11.80	10.30	10.20	11.80	11.00	10.50	10.40	10.55	10.90
26	10.15	11.40	10.95	11.70	10.20	10.20	11.40	11.40	10.45	10.40	10.60	10.80
27	10.10	11.25	10.90	11.60	10.20	10.10	11.10	13.50	10.40	10.45	10.60	10.85
28	11.00	11.30	10.90	11.50	10.20	10.05	11.10	11.60	10.40	10.40	10.60	10.70
29	11.70	.....	10.90	11.40	10.20	10.00	11.00	11.40	10.35	10.40	10.60	10.70
30	12.30	.....	10.85	11.30	10.15	9.95	10.95	11.30	10.35	10.40	10.60	10.75
31	11.50	.....	10.80	.....	10.20	.....	10.80	11.50	.....	10.45	.....	10.85

Daily gage height, in feet, of Verde River at McDowell, Arizona, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	6.70	7.50	7.80	7.15	6.80	6.80	6.70	8.30	8.80	6.80	6.80	7.20
2	6.70	7.40	7.90	7.15	6.95	6.80	6.70	7.70	8.50	6.80	6.80	7.20
3	6.75	7.35	8.00	7.20	7.10	6.80	6.70	7.50	8.80	6.80	6.80	7.20
4	6.75	7.30	8.05	7.30	7.10	6.80	6.70	7.30	7.80	6.75	6.80	7.20
5	6.75	7.30	8.05	7.40	7.10	6.80	6.65	7.40	7.60	6.75	6.80	7.20
6	6.75	7.40	7.70	7.35	7.10	6.80	7.15	7.50	7.50	6.80	6.90	7.15
7	6.75	7.35	7.70	7.30	7.15	6.80	6.95	7.80	7.40	6.80	6.95	7.15
8	6.75	7.45	7.70	7.30	7.10	6.80	6.90	7.30	7.35	6.80	6.95	7.15
9	6.75	7.40	7.80	7.30	7.05	6.80	7.20	7.00	7.30	6.80	7.00	7.20
10	6.85	7.55	7.75	7.30	7.00	6.80	7.10	7.00	7.20	6.80	6.90	7.20
11	6.95	7.50	7.80	7.35	7.00	6.85	7.00	6.95	7.10	6.80	6.90	7.40
12	7.05	7.30	8.20	7.30	7.00	6.85	7.05	7.00	7.05	6.80	6.95	7.45
13	7.00	7.20	8.00	7.30	7.00	6.85	7.05	6.90	7.00	6.80	6.95	7.55
14	6.85	7.15	8.00	7.25	6.95	6.85	7.20	6.85	6.95	6.80	7.00	7.50
15	6.90	7.15	8.05	7.25	6.85	6.85	7.25	6.75	7.10	6.80	7.00	7.45
16	6.85	7.20	7.60	7.20	6.95	6.90	9.45	6.85	7.00	6.80	7.00	7.55
17	6.85	7.40	7.00	7.15	6.85	6.90	8.20	6.90	7.00	6.80	7.00	7.50
18	6.85	7.50	7.40	7.15	6.90	6.85	8.35	6.85	7.00	6.80	7.00	7.60
19	6.80	7.50	7.80	7.15	6.90	6.80	7.90	7.00	7.00	6.80	7.05	7.60
20	6.80	7.60	7.40	7.15	6.95	6.85	7.50	7.00	6.90	6.80	7.05	7.50
21	6.85	7.50	7.30	7.15	6.95	6.85	7.30	6.95	6.90	6.80	7.05	7.45
22	6.85	7.50	7.30	7.15	6.95	6.85	7.10	6.95	6.90	6.85	7.10	7.40
23	6.85	7.50	7.20	7.10	6.95	6.85	7.00	7.75	6.90	6.85	7.10	7.40
24	6.85	7.50	7.20	7.10	6.95	6.90	7.00	7.30	6.90	6.90	7.10	7.40
25	6.85	7.60	7.20	7.10	6.90	6.95	7.00	7.20	6.90	6.90	7.15	7.40
26	6.85	7.60	7.15	7.05	6.90	6.95	7.00	7.50	6.90	6.90	7.20	7.40
27	6.85	7.80	7.10	7.05	6.85	6.95	6.95	9.25	6.90	6.90	7.20	7.50
28	7.10	7.80	7.10	7.05	6.85	6.95	6.95	8.50	6.90	6.90	7.15	7.55
29	8.10	.....	7.15	7.00	6.85	6.85	6.80	8.40	6.80	6.90	7.20	7.55
30	8.80	.....	7.15	6.95	6.85	6.80	7.00	7.90	6.80	6.90	7.20	7.45
31	7.80	.....	7.15	.....	6.80	.....	6.80	7.85	.....	6.90	.....	7.40

Daily gage height, in feet, of Colorado River at Yuma, Arizona, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Sept.	Oct.	Nov.	Dec.
1	17.92	18.00	18.92	18.67	21.50	21.58	23.42	19.75	18.00	18.17	18.58
2	17.83	18.00	19.00	18.67	21.42	21.50	23.42	19.75	18.00	18.25	18.50
3	17.75	18.25	19.00	18.58	21.42	21.58	23.17	19.83	18.08	18.33	18.42
4	17.75	18.25	19.00	18.58	21.75	21.75	22.83	19.83	18.00	18.33	18.33
5	17.58	17.92	18.92	18.83	22.00	22.25	22.58	19.75	18.00	18.50	18.33
6	17.58	18.00	18.83	18.67	22.00	22.58	22.25	19.83	18.00	18.58	18.33
7	17.58	17.83	18.75	18.50	22.00	22.75	22.00	19.67	18.00	18.58	18.42
8	17.50	17.75	18.67	18.50	22.00	22.83	21.83	19.42	18.00	18.50	18.42
9	17.50	18.00	18.67	18.67	21.75	22.92	21.67	19.17	18.00	18.58	18.58
10	17.83	18.08	18.75	19.00	21.58	23.17	21.50	19.00	18.00	18.50	18.58
11	17.75	18.33	19.00	19.08	21.33	23.17	21.33	19.08	18.00	18.50	18.58
12	17.75	18.17	19.08	18.92	21.25	23.00	21.25	19.00	18.00	18.50	18.50
13	17.92	18.17	19.25	18.67	21.17	22.92	21.50	18.92	17.92	18.50	18.50
14	18.08	18.17	19.08	18.50	21.17	22.67	21.50	18.83	17.92	18.50	18.50
15	18.42	18.25	18.92	18.75	21.17	22.58	21.42	18.83	17.92	18.50	18.50
16	18.58	18.42	18.75	18.92	21.00	22.50	21.33	18.75	17.92	18.58	18.58
17	18.75	18.50	18.75	18.83	20.83	22.42	21.50	18.67	17.83	18.67	18.75
18	18.75	18.58	18.92	18.92	20.83	22.33	21.33	18.58	17.83	18.75	18.92
19	18.75	18.58	18.92	19.00	20.92	22.42	21.25	18.75	17.83	18.83	19.00
20	18.83	18.50	18.83	20.08	21.17	22.33	21.08	18.75	17.83	18.83	18.83
21	18.83	18.58	18.92	20.17	21.50	22.33	21.08	18.58	17.83	18.92	18.67
22	18.75	18.67	19.17	20.25	21.67	22.50	21.50	18.42	17.83	18.92	18.42
23	18.50	18.92	19.08	21.17	21.75	22.75	22.00	18.42	17.83	18.92	18.17
24	18.42	18.92	19.08	21.08	21.75	23.08	21.92	18.42	17.83	18.75	18.00
25	18.25	18.92	18.83	21.67	21.67	23.25	21.50	18.42	17.83	18.75	17.92
26	18.42	18.92	18.75	21.75	21.83	23.50	21.17	18.42	18.00	18.75	17.75
27	18.50	18.92	18.67	21.58	21.75	23.50	21.00	18.33	18.00	18.75	17.67
28	18.33	18.92	18.67	21.50	21.50	23.50	20.50	18.25	18.08	18.75	17.67
29	18.17	.....	18.67	21.50	21.50	23.50	20.33	18.17	18.17	18.67	17.58
30	18.17	.....	18.75	21.50	21.50	23.42	20.17	18.00	18.17	18.67	17.50
31	18.08	.....	18.67	.....	21.42	.....	20.17	.....	18.17	.....	17.58

Data furnished by United States Commission of Fish and Fisheries.

List of discharge measurements, 1898.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
				Feet.	*Sec.-feet.*
Apr. 29	Black Fork River	Granger, Wyo	C. T. Johnston	3.20	1,962
May 21	do	do	do	2.60	1,727
June 18	do	do	do	3.40	2,401
June 29	do	do	do	2.30	1,328
Apr. 29	Green River	Greenriver, Wyo	do	2.60	3,803
May 21	do	do	do	3.00	a 4,239
Do.	do	do	do	2.95	b 3,966
June 18	do	do	do	4.50	11,696
June 28	do	do	do	5.05	14,252
Apr. 25	Grand River	Grand Junction, Colo.	A. L. Fellows	5.15	4,802
May 23	do	do	do	5.85	6,067
June 27	do	do	do	7.40	11,215
Aug. 27	do	do	do	3.35	1,237
Oct. 15	do	do	do	3.20	949
Apr. 5	Uncompahgre River.	Fort Crawford, Colo.	do	3.55	91
May 9	do	do	do	3.92	203
June 15	do	do	do	5.18	720
Aug. 12	do	do	do	3.80	74
Oct. 16	do	do	do	3.75	56
Apr. 28	Gunnison River	Grand Junction, Colo.	do	4.65	5,932
May 23	do	do	do	4.50	4,647
June 28	do	do	do	4.62	5,274
Aug. 27	do	do	do	1.80	866
Oct. 15	do	do	do	1.50	578
Apr. 7	San Miguel River	Fallcreek, Colo	do	2.50	66
May 11	do	do	do	3.30	270
June 16	do	do	do	4.40	841
Aug. 13	do	do	do	2.80	133
Oct. 17	do	do	do	2.30	30
Apr. 9	Mancos River	Mancos, Colo	do	1.80	102
May 14	do	do	do	2.20	185
June 18	do	do	do	2.00	160
Aug. 20	do	do	do	1.00	5
Oct. 18	do	do	do	.80	3
Apr. 8	Dolores River	Dolores, Colo	do	3.15	325
May 12	do	do	do	4.30	1,163
June 17	do	do	G. H. Matthes	4.80	1,870
Aug. 16	do	do	do	2.80	102
Sept. 11	do	do	do	2.70	72
Sept. 28	do	do	A. L. Fellows	2.55	46
Oct. 21	do	do	do	2.55	40
Apr. 12	San Juan River	Arboles, Colo	do	7.30	1,408
May 17	do	do	do	7.42	1,497
June 21	do	do	do	8.10	2,579
Aug. 8	do	do	G. H. Matthes	6.30	294
Aug. 23	do	do	A. L. Fellows	6.05	213
Oct. 23	do	do	do	5.80	83
Apr. 13	Piedra River	do	do	4.80	1,158
May 16	do	do	do	4.52	987
June 22	do	do	do	5.10	1,315
Aug. 8	do	do	G. H. Matthes	3.10	196
Aug. 24	do	do	A. L. Fellows	3.05	186
Oct. 24	do	do	do	2.60	52
Apr. 11	Animas River	Durango, Colo	do	6.50	1,356
May 15	do	do	do	7.25	1,797
June 20	do	do	do	8.55	3,475
Aug. 5	do	do	G. H. Matthes	5.20	414
Aug. 22	do	do	A. L. Fellows	5.07	284
Oct. 22	do	do	do	4.70	160
Mar. 7	Gila River	Buttes, Ariz	A. T. Colton	2.80	373
Mar. 29	do	do	do	2.50	606
Apr. 12	do	do	do	2.40	291
Apr. 23	do	do	do	3.25	855
May 17	do	do	do	2.50	182
June 8	do	do	do	2.00	27
June 22	do	do	do	2.10	32
July 6	do	do	do	4.55	2,902
July 19	do	do	do	4.00	2,134
July 29	do	do	do	3.15	709
Aug. 8	do	do	do	2.90	590
Aug. 22	do	do	do	2.70	466
Oct. 10	do	do	do	1.90	59
Nov. 14	do	do	C. C. Babb	1.90	94
Nov. 25	do	do	do	2.10	125
Dec. 14	do	do	do	2.70	305
Dec. 24	do	do	do	2.95	382
Nov. 28	Florence Canal	Bridge 2 miles east of Florence.	do	.....	76
Do.	do	White's ranch near head gate.	do	.....	100

a 5 a. m. b 2 p. m.

List of discharge measurements, 1898—Continued.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
				Feet.	*Sec.-feet.*
Jan. 8	Salt River	McDowell, Ariz.	W. A. Farish	10.10	288
Jan. 30	do	do	do	12.10	1,064
Feb. 27	do	do	do	11.40	545
Mar. 13	do	do	do	11.57	856
Mar. 20	do	do	do	11.20	688
Apr. 10	do	do	do	11.35	768
Apr. 24	do	do	do	11.90	999
May 28	do	do	do	10.20	295
May 29	do	do	do	10.20	257
June 13	do	do	do	10.10	233
June 26	do	do	do	10.10	296
July 18	do	do	do	12.25	1,057
Aug. 7	do	do	do	10.80	398
Aug. 22	do	do	do	10.70	425
Aug. 29	do	do	do	11.40	650
Sept. 28	do	do	do	10.37	195
Sept. 29	do	do	do	10.37	178
Oct. 27	do	do	do	10.40	186
Oct. 28	do	do	do	10.35	196
Nov. 27	do	do	do	10.55	260
Nov. 28	do	do	do	10.60	229
Dec. 25	do	do	do	10.75	287
Dec. 26	do	do	do	10.70	284
Jan. 7	Verde River	do	do	6.75	323
Jan. 30	do	do	do	8.25	1,868
Mar. 13	do	do	do	8.00	956
Mar. 20	do	do	do	7.40	481
Apr. 10	do	do	do	7.30	382
Apr. 24	do	do	do	7.05	234
May 28	do	do	do	6.85	127
May 29	do	do	do	6.85	130
June 13	do	do	do	6.80	142
June 26	do	do	do	7.00	152
July 18	do	do	do	8.30	991
Aug. 7	do	do	do	7.45	258
Aug. 22	do	do	do	7.00	205
Aug. 29	do	do	do	7.40	592
Sept. 28	do	do	do	6.90	142
Sept. 29	do	do	do	6.80	175
Oct. 27	do	do	do	6.95	209
Oct. 28	do	do	do	6.85	220
Nov. 27	do	do	do	7.20	290
Nov. 28	do	do	do	7.15	287
Dec. 25	do	do	do	7.45	281
Dec. 26	do	do	do	7.40	332

List of miscellaneous discharge measurements, 1898.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
				Feet.	*Sec.-feet.*
Aug. 6	Los Pinos River	6 miles above Ignacio, Colo.	G. H. Matthes		246
Aug. 7	Do	4 miles below Ignacio, Colo.	do		196
Aug. 10	La Plata River	Hesperus, Colo.	do		11
Aug. 18	San Juan River	Noland, Utah	do		609
Sept. 14	White River	Meeker, Colo	A. L. Fellows		300
Sept. 15	Williams River	Hamilton, Colo.	do		25
Sept. 17	Yampa River	8 miles below Hayden, Colo.	do		111
Do.	Elk River	Near mouth, Trull post-office, Colo.	do		63
Sept. 18	Yampa River	Steamboat Springs, Colo.	do		65
Sept. 19	Snake River	Honnold post-office, Colo.	do		17
Sept. 20	Slater Fork of Snake River.	Slater post-office, Colo.	do		9
Sept. 21	Little Snake River.	Dixon, Wyo.	do		19
Do.	San Juan River	Noland, Utah	G. H. Matthes		383
Sept. 22	Yampa River	Below Maybell, Colo.	A. L. Fellows		99
Sept. 24	Green River	6 miles below Ladore, Colo.	do		552
Sept. 26	Yampa River	Craig, Colo	do		79

Rating tables.

Granger.		Green river.		Blake.		Grand Junction. *a*		Grand Junction. *b*		Fort Crawford. *c*	
Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*
0.0	155	0.9	400	1.0	1,000	0.0	0	2.9	464	3.3	47
.1	170	1.0	500	1.2	1,080	.1	15	3.0	561	3.4	62
.2	190	1.1	640	1.4	1,160	.2	33	3.1	755	3.5	81
.3	210	1.2	800	1.6	1,250	.3	50	3.2	949	3.6	105
.4	230	1.3	960	1.8	1,400	.4	70	3.3	1,143	3.7	133
.5	250	1.4	1,120	2.0	1,600	.5	92	3.4	1,337	3.8	163
.6	270	1.5	1,280	2.2	2,020	.6	113	3.5	1,531	3.9	195
.7	290	1.6	1,440	2.4	2,440	.7	137	3.6	1,725	4.0	228
.8	320	1.7	1,600	2.6	2,860	.8	162	3.7	1,919	4.1	263
.9	350	1.8	1,760	2.8	3,280	.9	195	3.8	2,113	4.2	299
1.0	390	1.9	1,920	3.0	3,700	1.0	228	3.9	2,307	4.3	337
1.2	470	2.0	2,080	3.2	4,120	1.1	268	4.0	2,500	4.4	376
1.4	550	2.1	2,240	3.4	4,540	1.2	314	4.2	2,888	4.5	416
1.6	670	2.2	2,400	3.6	4,960	1.3	396	4.4	3,276	4.6	457
1.8	830	2.3	2,600	3.8	5,380	1.4	560	4.6	3,664	4.7	499
2.0	1,000	2.4	2,800	4.0	5,800	1.5	723	4.8	4,052	4.8	543
2.2	1,180	2.5	3,000	4.2	6,220	1.6	887	5.0	4,439	4.9	588
2.4	1,380	2.6	3,200	4.4	6,640	.....	.....	5.2	4,827	5.0	634
2.6	1,625	2.7	3,400	4.6	7,300	.....	.....	5.4	5,215	5.1	681
2.8	1,875	2.8	3,650	4.8	8,100	.....	.....	5.6	5,603	5.2	728
3.0	2,125	2.9	4,000	5.0	9,000	.....	.....	5.8	5,991	5.3	774
3.2	2,375	3.0	4,400	5.2	10,200	.....	.....	6.0	6,398	5.4	821
3.4	2,625	3.2	5,280	5.4	11,800	.....	.....	6.5	7,768	5.5	868
3.6	2,875	3.4	6,240	5.6	13,700	.....	.....	7.0	9,578	5.6	915
3.8	3,125	3.6	7,200	5.8	15,600	.....	.....	7.5	11,645	5.7	962
4.0	3,375	3.8	8,160	6.0	17,500	.....	.....	8.0	13,795	5.8	1,009
4.5	4,000	4.0	9,120	6.5	22,250	.....	.....	8.5	15,945	.....	.....
5.0	4,625	4.5	11,520	7.0	27,000	.....	.....	.....	.....	.....	.....
5.5	5,250	5.0	13,920	7.5	31,750	.....	.....	.....	.....	.....	.....
.....	.....	.....	.....	8.0	36,500	.....	.....	.....	.....	.....	.....

a Rating table for rod No. 1 on Grand River.
b Rating table for rod No. 2 on Grand River.
c Applicable from April 9 to June 25, 1898.

Fort Crawford. *a*		Grand Junction. *b*		Fall Creek.		Mancos.		Dolores.	
Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Sec.-feet.*	*Feet.*	*Sec.-feet.*	*Feet.*	*Sec.-feet.*	*Feet.*	*Sec.-feet.*	*Feet.*	*Sec.-feet.*
3.5	15	1.2	311	2.3	30	0.7	2	2.0	0
3.6	28	1.3	399	2.4	47	.8	3	2.1	3
3.7	46	1.4	487	2.5	66	.9	4	2.2	8
3.8	74	1.5	578	2.6	87	1.0	6	2.3	14
3.9	110	1.6	672	2.7	109	1.1	8	2.4	23
4.0	157	1.7	768	2.8	133	1.2	12	2.5	34
4.1	204	1.8	866	2.9	157	1.3	19	2.6	50
4.2	251	1.9	968	3.0	183	1.4	29	2.7	72
4.3	298	2.0	1,076	3.1	210	1.5	42	2.8	102
4.4	345	2.2	1,306	3.2	239	1.6	60	2.9	144
4.5	392	2.4	1,544	3.3	270	1.7	81	3.0	198
4.6	449	2.6	1,790	3.4	304	1.8	102	3.1	260
4.7	496	2.8	2,044	3.5	342	1.9	123	3.2	326
4.8	543	3.0	2,306	3.6	382	2.0	144	3.3	395
4.9	588	3.2	2,577	3.7	425	2.1	165	3.4	467
5.0	634	3.4	2,861	3.8	470	2.2	186	3.5	542
5.1	681	3.6	3,158	3.9	519	2.3	207	3.6	620
5.2	728	3.8	3,467	4.0	571	2.4	228	3.7	701
5.3	774	4.0	3,791	4.1	629	2.5	249	3.8	784
5.4	821	4.2	4,158	4.2	692	2.6	270	3.9	869
5.5	868	4.4	4,636	4.3	760	2.7	291	4.0	956
5.6	915	4.6	5,316	4.4	832	2.8	312	4.1	1,045
5.7	962	4.8	6,168	4.5	907	2.9	333	4.2	1,136
5.8	1,009	5.0	7,104	4.6	984	3.0	354	4.3	1,229
.....	.....	5.2	8,050	4.7	1,062	3.1	375	4.4	1,324
.....	.....	5.4	8,996	4.8	1,140	.....	.....	4.5	1,421
.....	.....	5.6	9,942	4.9	1,218	.....	.....	4.6	1,520
.....	.....	5.8	10,888	5.0	1,296	.....	.....	4.7	1,620
.....	.....	6.0	11,834	5.1	1,374	.....	.....	4.8	1,721
.....	.....	.....	.....	.....	.....	.....	.....	4.9	1,823

a Applicable from June 26 to November 30, 1898.
b Rating table for Gunnison River.

Rating tables—Continued.

Arboles. *a*		Arboles. *b*		Durango.		McDowell. *c*		McDowell. *d*	
Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Sec.-feet.*	*Feet.*	*Sec.-feet.*	*Feet.*	*Sec.-feet.*	*Feet.*	*Sec.-feet.*	*Feet.*	*Sec.-feet.*
5.8	83	2.5	27	4.6	125	10.0	215	10.0	30
5.9	124	2.6	52	4.7	160	10.1	255	10.1	66
6.0	169	2.7	78	4.8	195	10.2	296	10.2	102
6.1	216	2.8	106	4.9	234	10.3	336	10.3	137
6.2	266	2.9	135	5.0	278	10.4	377	10.4	173
6.3	319	3.0	165	5.1	328	10.5	417	10.5	209
6.4	376	3.1	196	5.2	383	10.6	458	10.6	244
6.5	440	3.2	229	5.3	442	10.7	498	10.7	280
6.6	510	3.3	264	5.4	502	10.8	539	10.8	316
6.7	590	3.4	301	5.5	562	10.9	579	10.9	351
6.8	680	3.5	340	5.6	624	11.0	620	11.0	387
6.9	795	3.6	382	5.7	686	11.1	660	11.1	423
7.0	935	3.7	430	5.8	748	11.2	701	11.2	458
7.1	1,082	3.8	478	5.9	812	11.3	741	11.3	494
7.2	1,232	3.9	530	6.0	877	11.4	782	11.4	530
7.3	1,382	4.0	585	6.2	1,008	11.5	822	11.5	565
7.4	1,531	4.1	643	6.4	1,146	11.6	863	11.6	601
7.5	1,681	4.2	704	6.6	1,292	11.7	903	11.7	637
7.6	1,830	4.3	768	6.8	1,444	11.8	944	11.8	672
7.7	1,980	4.4	835	7.0	1,608	11.9	984	11.9	708
7.8	2,130	4.5	904	7.2	1,786	12.0	1,025	12.0	744
7.9	2,280	4.6	974	7.4	1,975	12.2	1,106	12.1	780
8.0	2,429	4.7	1,043	7.6	2,176	12.4	1,187	12.2	816
8.1	2,579	4.8	1,112	7.8	2,394	12.6	1,268	12.3	851
8.2	2,729	4.9	1,182	8.0	2,638	12.8	1,349	12.4	887
8.3	2,879	5.0	1,251	8.2	2,910	13.0	1,430	12.5	923
8.4	3,029	5.1	1,321	8.4	3,220	13.2	1,511	12.6	958
8.5	3,180	5.2	1,390	8.6	3,570	13.4	1,592	12.7	994
8.6	3,330	5.3	1,459	8.8	3,952	13.6	1,673	12.8	1,030
.....	.....	5.4	1,529	9.0	4,358	13.8	1,754	12.9	1,065

a Rating table for San Juan River.
b Rating table for Piedra River.
c Rating table for Salt River; applicable from January 1 to July 5, 1898.
d Rating table for Salt River; applicable from July 6 to December 31, 1898.

INTERIOR BASIN DRAINAGE.

DESCRIPTION OF RIVER STATIONS.

Peko station on North Fork of Humboldt River.—This station is at the Central Pacific Railroad bridge, about 2 miles west of Peko station, Nevada. It was established by Mr. L. H. Taylor, March 25, 1898. The observer is James Courtney, post-office, Halleck, Nevada. The gage consists of a vertical timber, divided to feet and tenths, spiked to the pile support of the railroad bridge. The bench mark is on the stone abutment on the east end of the bridge on the left bank of the stream, 12 feet above the zero of the gage. The initial point for soundings is on the left bank, at the bench mark. The channel above and below the station is curved and the water is moderately swift. A small side channel enters immediately above the bridge and another channel takes water from the main stream at a still higher point during high stages, but during medium and low water it is dry. Measurements are made from the upper side of the bridge. The bed of the stream is of sand and gravel, shifting somewhat during high water.

Elko station on Humboldt River.—Described on page 152 of Paper No. 16; results for 1897 given on pages 424–426 of the Nineteenth

Annual Report, Part IV. The observer was John Garrecht until September 10; since that date, Addit T. Garrecht.

Golconda station on Humboldt River.—Described on page 154 of Paper No. 16; results for 1897 given on pages 427 of the Nineteenth Annual Report, Part IV.

Oreana station on Humboldt River.—Described on page 155 of Paper No. 16; results for 1897 given on pages 428–429 of the Nineteenth Annual Report, Part IV.

Masons Ranch station on South Fork of Humboldt River.—Described on page 156 of Paper No. 16; results for 1897 given on pages 429–430 of the Nineteenth Annual Report, Part IV. The observer for balance of year, after March 12, was Joe Pattain.

Soda Springs station on Bear River.—This station was established May 25, 1896, by Mr. F. J. Mills, State engineer of Idaho. It is located at the wagon bridge, about 1 mile southwest of the town of Soda Springs, Idaho. The cross section is inferior, owing to its being obstructed by four bridge piers. The drainage area at this point is 3,540 square miles.

Battle Creek station on Bear River.—Described on page 157 of Paper No. 16; results for 1897 given on pages 431–433 of the Nineteenth Annual Report, Part IV.

Logan station on Logan River.—Described on page 158 of Paper No. 16; results for 1897 given on pages 433–434 of the Nineteenth Annual Report, Part IV.

Collinston station on Bear River.—Described on page 159 of Paper No. 16; results for 1897 given on pages 434–435 of the Nineteenth Annual Report, Part IV. The observer was F. C. Engelke, after August 13, 1898. Discharge measurements were made in 1898 by J. L. Rhead, Samuel Fortier, and J. S. Baker.

Ogden station on Ogden River.—Described on page 160 of Paper No. 16; results for 1897 given on pages 436–439 of the Nineteenth Annual Report, Part IV. Discharge measurements made in 1898 by J. S. Baker.

Uinta station on Weber River.—Described on page 161 of Paper No. 16; results for 1897 given on pages 440–441 of the Nineteenth Annual Report, Part IV. Discharge measurements in 1898 made by J. S. Baker.

Provo station on Provo River.—Described on page 162 of Paper No. 16; results for 1897 given on pages 441–442 of the Nineteenth Annual Report, Part IV. Discharge measurements made in 1898 by W. B. Dougall and J. S. Baker.

Geneva station on Utah Lake.—Described on page 163 of Paper No. 16; results for 1897 given on page 443 of the Nineteenth Annual Report, Part IV.

TABLES OF DAILY GAGE HEIGHT.

Daily gage height, in feet, of North Fork of Humboldt River at Peko, Nevada, for 1898.

Day.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	.....	2.70	3.00	3.20	2.20	1.80	1.45	1.50	1.90	2.40
2	.....	2.70	3.10	3.10	2.10	1.80	1.45	1.80	1.90	2.40
3	.....	2.70	3.20	2.90	2.20	1.80	1.45	1.80	2.00	2.40
4	.....	2.70	2.90	2.95	2.30	1.80	1.45	1.80	2.00	2.30
5	.....	2.70	3.00	2.90	2.30	1.75	1.45	1.80	2.00	2.30
6	.....	2.75	2.90	3.10	2.10	1.80	1.45	1.80	1.90	2.40
7	.....	2.75	3.10	2.95	2.20	1.80	1.50	1.80	1.90	2.40
8	.....	2.70	3.70	3.05	2.10	1.80	1.50	1.80	1.90	2.40
9	.....	2.70	3.70	3.00	2.00	1.85	1.45	1.80	2.00	2.30
10	.....	2.75	3.75	3.10	2.10	1.85	1.45	1.80	2.00	2.30
11	.....	2.75	3.40	3.20	2.10	1.85	1.45	1.80	2.00	2.20
12	.....	3.20	3.00	2.90	2.10	1.80	1.45	1.80	2.00	2.30
13	.....	3.30	3.20	2.80	2.20	1.80	1.45	1.80	2.10	2.30
14	.....	3.50	3.00	2.60	2.10	1.80	1.45	1.80	2.20	2.30
15	.....	3.45	3.00	2.70	2.00	1.80	1.50	1.80	2.20	2.30
16	.....	3.35	3.15	2.80	2.00	1.75	1.45	1.80	2.30	2.40
17	.....	3.30	3.75	2.80	2.00	1.75	1.50	1.80	2.40	2.40
18	.....	3.60	3.75	2.75	2.00	1.75	1.50	1.80	2.40	2.20
19	.....	3.35	3.20	2.00	2.00	1.75	1.50	1.80	2.40	2.20
20	.....	3.00	3.55	2.10	1.90	1.75	1.45	1.80	2.20	2.30
21	.....	3.65	3.15	2.20	1.80	1.70	1.45	1.80	2.20	2.30
22	.....	3.20	3.70	2.45	1.80	1.70	1.45	1.80	2.30	2.30
23	.....	3.20	3.35	3.00	1.80	1.60	1.50	1.90	2.30	2.30
24	.....	3.00	3.70	3.00	1.90	1.60	1.50	1.90	2.20	2.30
25	2.65	3.30	3.75	2.90	1.90	1.50	1.45	1.90	2.20	2.30
26	2.65	3.10	3.00	2.90	2.00	1.50	1.45	1.80	2.20	2.30
27	2.70	2.90	3.10	2.85	2.00	1.45	1.45	1.80	2.20	2.40
28	2.70	2.75	3.70	2.65	2.10	1.45	1.50	1.80	2.20	2.40
29	2.70	2.90	2.90	2.20	2.10	1.45	1.50	1.80	2.30	2.40
30	2.75	2.90	2.95	2.20	2.00	1.50	1.50	1.90	2.40	2.30
31	2.75	.....	3.05	.....	1.90	1.50	.....	1.90	.....	2.30

Daily gage height, in feet, of Humboldt River, at Elko, Nevada, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	2.40	2.30	4.30	2.80	3.40	4.05	3.00	1.75	1.65	1.80	1.80	2.00
2	2.45	2.30	4.20	2.80	3.65	4.10	3.00	1.75	1.65	1.80	1.85	2.00
3	2.40	2.30	4.00	2.85	3.70	4.10	2.80	1.75	1.65	1.80	1.85	2.00
4	2.40	2.30	4.50	2.90	3.75	4.05	2.80	1.75	1.65	1.85	1.85	2.10
5	2.40	2.30	4.30	3.00	3.80	4.00	2.50	1.75	1.65	1.85	1.85	2.15
6	2.40	2.30	4.00	3.00	3.75	3.90	2.50	1.70	1.65	1.85	1.85	2.10
7	2.40	2.35	4.00	3.00	3.75	3.80	2.50	1.70	1.65	1.85	1.85	2.05
8	2.40	2.40	3.90	3.00	3.70	3.75	2.50	1.70	1.65	1.85	1.85	2.05
9	2.40	2.40	3.90	3.00	3.60	3.70	2.50	1.70	1.65	1.75	1.85	2.05
10	2.35	2.40	3.80	3.00	3.50	3.70	2.45	1.70	1.65	1.75	1.85	2.05
11	2.35	2.40	3.85	3.00	3.60	3.70	2.35	1.70	1.70	1.75	1.90	2.05
12	2.35	2.40	3.80	3.00	3.15	3.70	2.30	1.70	1.70	1.75	1.90	2.05
13	2.40	2.60	3.50	3.10	3.10	3.75	2.30	1.70	1.70	1.75	1.90	2.00
14	2.40	2.75	3.30	3.10	3.10	3.75	2.30	1.70	1.70	1.75	1.90	2.00
15	2.40	2.80	3.20	3.10	3.20	3.80	2.30	1.65	1.70	1.75	1.90	2.00
16	2.30	3.00	3.00	3.15	3.15	3.80	2.30	1.65	1.70	1.75	1.95	2.00
17	2.35	3.50	3.00	3.20	3.25	3.85	2.30	1.65	1.70	1.80	1.90	2.00
18	2.35	3.65	2.90	3.20	3.50	3.90	2.25	1.65	1.70	1.80	1.90	2.00
19	2.35	3.80	2.90	3.20	3.80	3.90	2.20	1.65	1.70	1.80	1.90	2.00
20	2.30	3.50	3.00	3.20	3.95	3.90	2.10	1.65	1.70	1.80	1.90	1.95
21	2.25	3.60	2.90	3.25	4.10	3.90	2.00	1.65	1.70	1.80	1.90	1.95
22	2.25	3.70	2.90	3.30	4.20	3.90	1.95	1.65	1.70	1.80	1.90	1.95
23	2.35	3.70	2.85	3.30	4.20	3.80	1.95	1.65	1.70	1.75	1.95	1.95
24	2.30	3.70	2.80	3.30	4.10	3.80	1.95	1.65	1.70	1.80	1.95	1.95
25	2.30	3.75	2.80	3.35	4.10	3.75	1.95	1.65	1.70	1.80	1.95	1.95
26	2.35	3.80	2.80	3.40	4.10	3.50	1.85	1.65	1.70	1.80	1.95	1.95
27	2.35	4.40	2.80	3.40	4.10	3.40	1.80	1.65	1.70	1.80	1.95	1.95
28	2.30	4.50	2.80	3.40	4.10	3.25	1.80	1.65	1.80	1.80	1.95	1.95
29	2.30	.....	2.80	3.40	4.05	3.10	1.75	1.65	1.80	1.80	2.00	1.95
30	2.45	.....	2.80	3.40	4.00	3.00	1.75	1.65	1.80	2.00	1.95	1.95
31	2.40	.....	2.80	.....	4.05	.....	1.75	1.65	.....	1.80	.....	1.95

Daily gage height, in feet, of Humboldt River at Golconda, Nevada, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	2.80	2.60	4.20	3.50	1 40	3.50	2.70	1.00	0.30	0.10	0.20	0.20
2	2.80	2.60	4.20	3.50	1.50	3.50	2.60	.90	.30	.10	.20	.20
3	2.80	2.60	4.20	3.40	1.40	3.60	2.60	.80	.30	.10	.20	.20
4	2.80	2.60	4.20	3.30	1.40	3.70	2.60	.80	.30	.10	.20	.20
5	2.80	2.60	4.15	3.20	1.30	3.70	2.60	.70	.20	.10	.20	.20
6	2.80	2.60	4.15	3.20	1.20	3.70	2.60	.70	.20	.10	.20	.20
7	2.85	2.60	4.15	3.10	1.20	3.70	2.50	.70	.20	.10	.20	.20
8	2.75	2.60	4.15	3.10	1.10	3.70	2.50	.70	.20	.10	.20	.20
9	2.75	2.60	4.20	3.00	1.00	3.60	2.50	.70	.20	.10	.20	.20
10	2.75	2.60	4.30	2.90	.95	3.50	2.50	.60	.20	.10	.20	.20
11	2.70	2.60	4.20	2.90	.90	3.30	2.40	.60	.20	.20	.20	.20
12	2.70	2.60	4.20	2.85	1.00	3.20	2.30	.60	.10	.20	.20	.30
13	2.70	2.60	4.30	2.80	1.30	3.00	2.30	.60	.10	.20	.20	.40
14	2.70	2.60	4.40	2.70	1.40	2.90	2.20	.60	.10	.20	.20	.50
15	2.75	2.70	4.50	2.60	1.50	2.80	2.10	.60	.00	.20	.20	.50
16	2.75	2.80	4.50	2.50	1.50	2.70	2.10	.50	.00	.20	.20	.60
17	2.75	3.00	4.50	2.50	1.60	2.70	2.10	.50	.00	.20	.20	.60
18	2.70	3.20	4.50	2.40	1.60	2.60	1.90	.40	.00	.20	.20	.60
19	2.70	3.40	4.20	2.30	1.50	2.50	1.80	.40	.00	.20	.20	.60
20	2.70	3.50	4.00	2.20	1.50	2.50	1.70	.40	.00	.20	.20	.60
21	2.70	3.50	4.00	2.00	1.50	2.50	1.60	.40	.00	.20	.20	.60
22	2.70	3.70	3.90	2.00	1.50	2.50	1.60	.40	.00	.20	.20	.60
23	2.60	3.90	3.90	2.10	1.50	2.50	1.50	.40	.00	.20	.20	.60
24	2.60	4.00	3.90	2.10	1.60	2.30	1.50	.40	.00	.20	.20	.70
25	2.60	4.20	3.85	2.10	2.10	2.50	1.50	.40	.00	.20	.20	.70
26	2.60	4.30	3.85	2.00	2.60	2.60	1.40	.30	.00	.20	.20	.70
27	2.60	4.20	3.80	1.90	2.80	2.60	1.30	.30	.00	.20	.20	.80
28	2.60	4.20	3.80	1.70	3.00	2.60	1.20	.30	.00	.20	.20	.70
29	2.60	.....	3.75	1.50	3.10	2.70	1.10	.30	.00	.20	.20	.70
30	2.60	.....	3.70	1.50	3.40	2.70	1.00	.30	.00	.20	.20	.70
31	2.60	.....	3.60	.....	3.50	.....	1.00	.30	.....	.20	.....	.70

Daily gage height, in feet, of Humboldt River at Oreana, Nevada, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	Day.	Jan.	Feb.	Mar.	Apr.	May.	June.
1	3.10	3.10	4.10	3.30	1.80	1.30	17	3.20	3.20	3.90	2.50	1.45	1.50
2	3.10	3.10	4.20	3.20	1.70	1.30	18	3.20	3.25	3.80	2.40	1.45	1.41
3	3.10	3.10	4.20	3.20	1.65	1.25	19	3.15	3.30	3.60	2.35	1.45	1.35
4	3.10	3.10	4.30	3.20	1.60	1.25	20	3.15	3.30	3.50	2.30	1.45	1.30
5	3.10	3.10	4.40	3.20	1.60	1.25	21	3.15	3.35	3.40	2.30	1.40	1.30
6	3.15	3.10	4.50	3.10	1.60	1.25	22	3.15	3.40	3.30	2.25	1.40	1.30
7	3.15	3.10	4.50	3.10	1.55	1.25	23	3.10	3.50	3.30	2.20	1.40	1.30
8	3.20	3.10	4.50	3.10	1.55	1.25	24	3.10	3.60	3.20	2.10	1.35	1.30
9	3.15	3.10	4.60	3.00	1.50	1.25	25	3.10	3.80	3.20	2.05	1.35	1.25
10	3.15	3.10	4.60	2.90	1.50	1.25	26	3.10	4.00	3.20	2.00	1.30	1.25
11	3.15	3.10	4.50	2.85	1.50	1.25	27	3.10	4.00	3.20	2.00	1.30	1.25
12	3.10	3.10	4.50	2.85	1.50	1.25	28	3.10	4.00	3.20	1.95	1.30	1.25
13	3.10	3.10	4.45	2.80	1.50	1.25	29	3.10	.....	3.30	1.90	1.30	1.25
14	3.10	3.10	4.40	2.70	1.50	1.30	30	3.10	.....	3.30	1.85	1.30	1.20
15	3.15	3.15	4.20	2.60	1.50	1.40	31	3.10	.....	3.30	.....	1.30	.....
16	3.15	3.15	4.00	2.55	1.50	1.60							

Daily gage height, in feet, of South Fork of Humboldt River at Masons Ranch, Nevada, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	0.90	1.30	1.50	1.25	2.10	2.45	1.80	0.45	0.30	0.40	0.65	0.90
2	.85	1.30	1.45	1.25	2.00	2.30	1.80	.45	.30	.45	.65	.90
3	.85	1.20	1.45	1.25	2.00	2.35	1.70	.45	.30	.45	.65	.90
4	.85	1.20	1.40	1.25	1.95	2.30	1.60	.45	.35	.45	.65	.80
5	.85	1.20	1.40	1.20	1.90	2.35	1.45	.45	.35	.45	.65	.70
6	.85	1.25	1.35	1.20	1.80	2.20	1.35	.40	.35	.45	.65	.70
7	1.00	1.30	1.35	1.25	1.75	2.15	1.35	.40	.35	.45	.65	.70
8	1.00	1.30	1.35	1.25	1.70	2.25	1.30	.40	.35	.45	.65	.70
9	1.00	.95	1.35	1.20	1.70	2.35	1.30	.40	.35	.50	.65	.70
10	1.10	1.30	1.30	1.20	1.65	2.50	1.90	.40	.35	.50	.65	.70
11	1.50	1.00	1.25	1.25	1.65	2.50	1.20	.40	.30	.50	.65	.65
12	.95	1.25	1.25	1.30	1.90	2.70	1.20	.40	.30	.50	.65	.65
13	1.00	1.50	1.35	1.35	1.95	2.70	1.25	.40	.30	.50	.65	.65
14	1.00	2.20	1.25	1.40	2.10	2.80	1.15	.40	.30	.50	.65	.65
15	1.00	2.55	1.30	1.50	2.15	2.75	1.10	.40	.30	.55	.65	.65

Daily gage height, in feet, of South Fork of Humboldt River at Masons Ranch, Nevada, for 1898—Continued.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
16	1.05	2.75	1.00	1.60	2.20	2.80	1.05	.40	.30	.55	.65	.65
17	1.10	2.25	1.10	1.70	2.25	2.80	1.00	.35	.30	.55	.65	.65
18	1.05	2.30	1.30	1.70	2.35	2.90	.90	.35	.35	.55	.65	.65
19	1.10	2.30	1.30	1.70	2.75	2.80	.90	.35	.35	.55	.65	.65
20	1.10	2.10	1.30	1.70	2.70	2.70	.90	.35	.40	.55	.65	.65
21	1.05	2.55	1.30	1.90	2.45	2.50	.85	.30	.40	.55	.60	.65
22	1.10	2.30	1.20	1.85	2.40	2.40	.85	.30	.40	.60	.60	.65
23	1.05	1.55	1.25	1.75	2.30	2.40	.80	.30	.40	.60	.60	.65
24	1.00	1.60	1.20	1.70	2.20	2.35	.75	.30	.40	.60	.60	.65
25	1.00	1.50	1.30	1.75	2.10	2.30	.75	.30	.40	.60	.60	.70
26	1.05	1.45	1.30	1.90	2.10	2.30	.65	.30	.40	.60	.60	.80
27	1.10	1.55	1.30	2.10	2.10	2.20	.65	.30	.40	.60	.60	.80
28	1.10	1.60	1.30	2.10	2.50	2.00	.60	.30	.40	.65	.60	.90
29	1.20	.....	1.30	2.10	2.85	2.00	.60	.30	.40	.65	.80	.90
30	1.30	.....	1.30	2.00	2.65	1.85	.55	.30	.40	.65	.90	1.00
31	1.40	.....	1.30	.....	2.55	.....	.50	.30	.....	.65	.....	1.00

Daily gage height, in feet, of Bear River at Soda Springs, Idaho, for 1898.

Day.	May.	June.	July.	Day.	May.	June.	July.	Day.	May.	June.	July.
1	.....	7.10	6.30	12	.....	6.60	.....	23	6.80	6.60	.....
2	.....	7.10	.....	13	.....	.....	.....	24	6.85	6.60	.....
3	.....	7.10	.....	14	.....	6.55	.....	25	6.90	6.60	.....
4	.....	7.10	.....	15	.....	6.50	.....	26	6.90	6.60	.....
5	.....	7.10	.....	16	.....	6.60	.....	27	6.90	6.50	.....
6	.....	7.00	.....	17	.....	6.60	.....	28	7.20	6.40	.....
7	.....	7.00	.....	18	.....	6.60	.....	29	7.10	6.40	.....
8	.....	6.90	.....	19	.....	6.60	.....	30	7.10	6.40	.....
9	.....	6.90	.....	20	.....	6.60	.....	31	7.10	.....	.....
10	.....	6.90	.....	21	.....	6.60	.....				
11	.....	6.90	.....	22	6.90	6.60	.....				

Discontinued July 1.

Daily gage height in feet, of Bear River at Battle Creek, Idaho, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	1.90	2.00	1.85	1.90	3.70	3.70	2.70	1.50	1.40	1.40	1.60	1.60
2	1.90	2.00	1.85	1.90	3.70	3.70	2.60	1.50	1.40	1.40	1.60	1.60
3	1.90	2.00	1.90	2.00	3.60	3.60	2.60	1.50	1.40	1.40	1.60	1.30
4	1.90	2.00	1.90	2.00	3.60	3.60	2.50	1.50	1.40	1.40	1.60	1.60
5	1.90	2.05	1.95	2.10	3.60	3.60	2.50	1.40	1.40	1.40	1.60	1.60
6	1.90	1.90	1.05	2.20	3.60	3.50	2.50	1.40	1.40	1.40	1.60	1.60
7	1.90	1.90	1.95	2.40	3.55	3.50	2.40	1.40	1.40	1.40	1.60	1.60
8	1.90	1.90	1.95	2.50	3.50	3.50	2.30	1.40	1.40	1.40	1.60	1.60
9	1.90	1.90	2.00	2.70	3.50	3.40	2.30	1.40	1.40	1.40	1.60	1.60
10	1.90	1.90	2.00	3.00	3.50	3.40	2.20	1.40	1.40	1.40	1.60	1.60
11	1.90	1.90	1.90	3.20	3.45	3.40	2.20	1.40	1.40	1.40	1.60	1.60
12	2.00	1.90	1.90	3.20	3.40	3.40	2.20	1.40	1.40	1.40	1.60	1.60
13	2.10	1.80	1.90	3.20	3.40	3.30	2.10	1.40	1.40	1.40	1.60	1.60
14	2.10	1.70	1.90	3.30	3.35	3.30	2.10	1.40	1.40	1.50	1.60	1.60
15	2.10	1.70	1.90	3.30	3.30	3.30	2.10	1.40	1.40	1.50	1.60	1.60
16	2.10	1.60	1.90	3.40	3.30	3.20	2.10	1.40	1.40	1.50	1.60	1.60
17	2.10	1.60	1.90	3.40	3.35	3.00	2.00	1.40	1.40	1.50	1.60	1.60
18	2.10	1.60	1.90	3.50	3.40	3.00	2.00	1.40	1.40	1.50	1.60	1.60
19	2.10	1.60	1.90	3.60	3.50	3.00	1.90	1.40	1.40	1.50	1.60	1.60
20	2.10	1.60	1.90	3.70	3.50	3.00	1.80	1.40	1.40	1.50	1.60	1.60
21	2.10	1.60	1.90	3.70	3.50	3.00	1.80	1.40	1.40	1.50	1.60	1.60
22	2.10	1.60	1.90	3.80	3.50	3.00	1.80	1.40	1.40	1.50	1.60	1.60
23	2.00	1.60	1.60	3.90	3.40	2.90	1.80	1.40	1.40	1.50	1.60	1.60
24	2.00	1.60	1.60	3.90	3.40	2.90	1.70	1.40	1.40	1.50	1.60	1.60
25	2.00	1.60	1.80	3.90	3.30	2.90	1.70	1.40	1.40	1.50	1.60	1.60
26	2.00	1.70	1.80	3.85	3.40	2.90	1.70	1.40	1.40	1.50	1.60	1.60
27	2.00	1.70	1.70	3.80	3.50	2.90	1.70	1.40	1.40	1.60	1.60	1.60
28	2.00	1.80	1.70	3.80	3.60	2.80	1.60	1.40	1.40	1.60	1.60	1.60
29	2.00	.....	1.80	3.70	3.70	2.70	1.60	1.40	1.40	1.60	1.60	1.60
30	2.00	.....	1.80	3.70	3.70	2.70	1.50	1.40	1.40	1.60	1.60	1.60
31	2.00	.....	1.90	.....	3.70	.....	1.50	1.40	.....	1.60	.....	1.60

Daily gage height, in feet, of Logan River at Logan, Utah, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	2.50	2.55	2.50	2.50	3.40	3.75	3.35	2.85	2.75	2.60	2.60	2.55
2	2.50	2.55	2.50	2.50	3.39	3.80	3.30	2.85	2.75	2.60	2.60	2.55
3	2.50	2.55	2.50	2.50	3.30	3.80	3.30	2.85	2.75	2.65	2.60	2.60
4	2.55	2.55	2.50	2.50	3.25	3.80	3.25	2.85	2.70	2.65	2.60	2.50
5	2.55	2.55	2.50	2.45	3.25	3.70	3.20	2.80	2.70	2.65	2.60	2.45
6	2.55	2.55	2.50	2.50	3.25	3.70	3.20	2.80	2.70	2.65	2.60	2.45
7	2.55	2.55	2.50	2.55	3.35	3.65	3.15	2.80	2.70	2.65	2.60	2.40
8	2.55	2.55	2.50	2.55	3.35	3.70	3.15	2.80	2.70	2.65	2.60	2.30
9	2.55	2.55	2.55	2.55	3.35	3.75	3.10	2.80	2.65	2.65	2.60	2.70
10	2.55	2.50	2.50	2.65	3.40	3.75	3.10	2.75	2.65	2.65	2.60	2.40
11	2.50	2.50	2.40	2.75	3.70	3.75	3.00	2.75	2.65	2.65	2.60	2.30
12	2.50	2.50	2.45	2.85	3.65	3.75	3.05	2.75	2.65	2.65	2.60	2.35
13	2.50	2.50	2.45	2.85	3.65	3.75	3.05	2.75	2.65	2.60	2.55	2.40
14	2.50	2.50	2.50	2.95	3.65	3.75	3.05	2.75	2.65	2.60	2.50	2.40
15	2.50	2.55	2.50	3.00	3.65	3.75	3.05	2.90	2.65	2.60	2.55	2.45
16	2.55	2.55	2.45	3.15	3.65	3.75	3.00	2.80	2.65	2.60	2.55	2.45
17	2.55	2.50	2.45	3.25	3.65	3.75	3.00	2.75	2.65	2.60	2.55	2.45
18	2.55	2.45	2.45	3.20	3.65	3.75	3.00	2.75	2.65	2.60	2.55	2.45
19	2.55	2.50	2.50	3.15	3.65	3.75	3.00	2.75	2.65	2.60	2.55	2.45
20	2.55	2.50	2.50	3.25	3.60	3.70	3.00	2.75	2.65	2.60	2.55	2.45
21	2.55	2.55	2.50	3.45	3.55	3.65	2.95	2.90	2.60	2.60	2.55	2.45
22	2.55	2.50	2.50	3.30	3.60	3.60	2.95	2.90	2.60	2.60	2.55	2.40
23	2.55	2.45	2.45	3.25	3.60	3.70	2.95	2.90	2.60	2.60	2.55	2.35
24	2.55	2.45	2.45	3.25	3.70	3.65	2.95	2.90	2.60	2.60	2.55	2.35
25	2.55	2.50	2.45	3.30	3.70	3.60	2.90	2.85	2.60	2.60	2.55	2.40
26	2.50	2.55	2.45	3.50	3.65	3.55	2.90	2.80	2.60	2.60	2.55	2.50
27	2.60	2.50	2.45	3.55	3.65	3.50	2.85	2.80	2.60	2.60	2.50	2.55
28	2.60	2.50	2.45	3.50	3.85	3.45	2.85	2.75	2.60	2.60	2.55	2.55
29	2.60	.....	2.45	3.45	3.75	3.40	2.80	2.75	2.60	2.60	2.60	2.55
30	2.55	.....	2.50	3.40	3.75	3.40	2.80	2.75	2.60	2.60	2.60	2.55
31	2.55	.....	2.60	.....	3.75	.....	2.85	2.75	.....	2.60	.....	2.55

Daily gage height, in feet, of Bear River at Collinston, Utah, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	2.00	2.00	2.45	2.35	4.40	4.75	2.55	1.30	1.10	1.30	1.70	1.90
2	2.00	2.00	2.75	2.40	4.35	4.80	2.50	1.30	1.10	1.40	1.70	1.90
3	2.00	2.00	2.75	2.40	4.30	4.80	2.40	1.25	1.10	1.50	1.70	1.90
4	2.25	2.00	2.80	2.40	4.30	4.80	2.30	1.20	1.10	1.50	1.70	1.60
5	1.90	2.00	2.80	2.55	4.20	4.80	2.25	1.20	1.30	1.60	1.70	1.40
6	2.00	2.15	2.80	2.60	4.20	4.75	2.20	1.15	1.30	1.60	1.70	1.40
7	2.00	2.15	2.65	2.60	4.20	4.70	2.15	1.10	1.10	1.60	1.70	1.40
8	2.00	2.15	2.60	2.65	4.20	4.60	2.10	1.10	1.10	1.60	1.70	1.40
9	2.05	2.10	2.60	2.75	4.10	4.55	2.00	1.10	1.10	1.60	1.70	1.40
10	2.00	2.25	2.60	2.90	4.05	4.40	2.00	1.10	1.10	1.60	1.70	1.70
11	2.30	2.15	2.40	3.30	4.00	4.10	2.00	1.10	1.10	1.60	1.70	1.20
12	2.35	2.15	2.30	3.60	3.90	4.00	1.95	1.10	1.10	1.60	1.70	1.20
13	2.45	1.95	2.30	3.85	3.90	3.90	1.85	1.10	1.10	1.60	1.70	1.20
14	2.45	1.90	2.30	4.05	3.95	3.70	1.80	1.10	1.20	1.60	1.70	1.20
15	2.35	1.90	2.30	4.15	3.90	3.55	1.70	1.10	1.20	1.60	1.70	1.20
16	2.30	1.90	2.20	4.20	3.90	3.40	1.70	1.10	1.20	1.60	1.70	1.50
17	2.30	2.20	2.30	4.20	3.95	3.30	1.80	1.10	1.20	1.60	1.70	1.50
18	2.25	2.20	2.30	4.30	4.30	3.20	1.75	1.10	1.20	1.60	1.80	1.50
19	2.05	2.10	2.30	4.30	4.30	3.20	1.70	1.10	1.20	1.60	1.80	1.50
20	2.05	2.05	2.30	4.35	4.40	3.20	1.60	1.10	1.20	1.70	1.90	1.50
21	2.35	2.00	2.30	4.40	4.50	3.20	1.60	1.10	1.20	1.70	1.90	1.50
22	2.20	2.00	2.10	4.45	4.50	3.20	1.55	1.10	1.20	1.70	1.90	1.50
23	2.30	2.00	2.10	4.55	4.50	3.15	1.50	1.10	1.20	1.70	1.70	1.40
24	2.25	2.00	2.10	4.60	4.50	3.10	1.50	1.10	1.30	1.70	1.70	1.40
25	2.35	2.00	2.15	4.60	4.60	3.10	1.45	1.10	1.30	1.70	1.70	1.40
26	2.35	2.00	2.20	4.60	4.60	3.10	1.40	1.10	1.30	1.70	1.70	1.40
27	2.35	2.20	2.10	4.60	4.60	3.10	1.30	1.10	1.30	1.70	1.60	1.40
28	2.20	2.30	2.15	4.50	4.60	3.00	1.30	1.10	1.30	1.70	1.60	1.40
29	2.15	.....	2.20	4.50	4.60	2.85	1.30	1.10	1.30	1.70	1.70	1.30
30	2.05	.....	2.25	4.50	4.65	2.70	1.30	1.10	1.30	1.70	1.80	1.30
31	2.05	.....	2.30	.....	4.70	.....	1.30	1.10	.....	1.70	.....	1.30

Daily gage height, in feet, of Ogden River at Ogden, Utah, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	2.30	2.60	2.80	2.90	3.60	3.70	1.70	1.90	1.40	1.50	1.50	1.50
2	2.60	2.50	2.80	3.10	3.50	3.60	1.70	2.00	1.50	1.60	1.50	1.60
3	2.60	2.60	2.70	3.20	3.50	3.70	1.70	1.70	1.50	1.70	1.50	1.50
4	2.45	2.50	2.70	3.20	3.40	3.50	1.70	1.70	1.50	1.50	1.50	1.50
5	2.60	2.60	2.80	3.20	3.40	3.40	1.80	1.60	1.40	1.60	1.50	1.50
6	2.30	2.60	2.90	3.30	3.40	3.30	1.65	1.70	1.40	1.50	1.50	1.50
7	2.60	2.60	2.90	3.30	3.40	3.10	1.80	1.50	1.40	1.50	1.60	1.40
8	2.30	2.70	2.90	3.30	3.40	3.00	1.70	1.50	1.50	1.50	1.50	1.50
9	2.60	2.70	2.90	3.40	3.40	2.90	1.70	1.60	1.50	1.40	1.50	1.50
10	2.90	2.70	2.80	3.00	3.40	2.80	1.70	1.60	1.50	1.50	1.50	1.50
11	2.70	2.70	2.80	3.10	3.40	2.80	1.70	1.50	1.40	1.50	1.50	1.50
12	2.60	2.70	2.70	3.20	3.40	2.70	1.80	1.40	1.40	1.50	1.50	1.40
13	2.40	2.70	3.00	3.30	3.40	2.70	1.70	1.40	1.50	1.50	1.50	1.40
14	2.40	2.70	2.90	3.40	3.40	2.60	1.70	1.80	1.40	1.50	1.50	1.40
15	2.30	2.70	2.90	3.50	3.30	2.50	1.50	1.60	1.50	1.50	1.50	1.40
16	2.60	2.70	2.80	3.60	3.30	2.20	1.60	1.40	1.50	1.60	1.50	1.40
17	2.30	2.70	2.70	3.70	3.50	2.10	1.60	1.50	1.50	1.55	1.50	1.40
18	2.40	2.70	2.70	3.80	3.70	2.10	1.50	1.90	1.40	1.50	1.70	1.40
19	2.40	2.70	2.80	3.80	4.00	2.00	1.50	1.50	1.50	1.50	1.60	1.40
20	2.30	2.60	2.80	3.80	3.90	1.90	1.60	1.40	1.40	1.50	1.70	1.40
21	2.40	2.70	2.80	4.80	3.80	2.00	1.65	1.50	1.40	1.50	1.60	1.40
22	2.30	2.70	2.80	4.20	3.70	1.70	1.60	1.40	1.40	1.50	1.50	1.50
23	2.50	2.70	2.50	4.00	3.70	2.00	1.50	1.40	1.40	1.50	1.50	1.50
24	2.30	2.80	2.50	3.80	3.90	2.00	1.60	1.40	1.40	1.50	1.50	1.40
25	2.30	2.80	2.80	3.80	4.10	1.90	1.55	1.40	1.50	1.50	1.50	1.40
26	2.60	2.70	2.80	3.80	4.00	2.00	1.65	1.40	1.40	1.50	1.50	1.40
27	2.30	2.60	2.80	3.90	3.90	1.80	1.60	1.40	1.50	1.50	1.50	1.40
28	2.60	2.70	2.80	3.80	4.10	1.80	1.60	1.40	1.40	1.50	1.40	1.40
29	2.30	.....	2.70	3.60	4.00	1.80	1.60	1.40	1.50	1.50	1.50	1.50
30	2.60	.....	2.80	3.60	3.90	1.80	1.60	1.50	1.50	1.50	1.50	1.50
31	2.30	.....	2.80	.....	3.80	.....	1.60	1.50	.....	1.40	.....	1.40

Daily gage height, in feet, of Weber River at Uinta, Utah, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	1.40	1.40	1.80	1.70	3.55	2.50	2.00	1.15	1.10	1.30	1.70	1.75
2	1.40	1.40	1.80	1.70	3.45	2.50	1.95	1.00	1.10	1.40	1.70	1.70
3	1.40	1.40	1.80	1.85	3.40	2.50	1.75	1.00	1.10	1.40	1.70	1.70
4	1.40	1.40	1.80	2.00	3.40	2.50	1.60	1.00	1.10	1.40	1.70	1.70
5	1.40	1.40	1.80	2.00	3.40	2.50	1.60	1.00	1.10	1.40	1.70	1.70
6	1.40	1.40	1.80	2.15	3.30	2.40	1.50	1.00	1.10	1.40	1.70	1.70
7	1.40	1.40	1.85	2.15	3.25	2.40	1.50	.80	1.10	1.40	1.70	1.70
8	1.40	1.40	1.85	2.40	3.05	2.40	1.50	.80	1.10	1.40	1.70	1.70
9	1.50	1.40	1.75	2.40	2.95	2.40	1.50	.80	1.10	1.40	1.70	1.70
10	1.50	1.40	1.60	2.45	2.85	2.25	1.50	.80	1.10	1.40	1.70	1.70
11	1.50	1.40	1.65	2.55	2.95	2.00	1.40	.80	1.20	1.40	1.70	1.70
12	1.50	1.40	1.55	2.60	3.15	2.00	1.40	.80	1.20	1.40	1.70	1.70
13	1.50	1.40	1.55	2.70	3.35	1.90	1.40	.80	1.20	1.40	1.70	1.70
14	1.50	1.40	1.55	2.70	3.55	1.80	1.40	.95	1.20	1.40	1.70	1.70
15	1.50	1.40	1.55	2.70	3.65	1.65	1.40	1.00	1.20	1.40	1.70	1.70
16	1.40	1.40	1.55	2.75	3.75	1.60	1.40	1.00	1.20	1.50	1.70	1.70
17	1.40	1.40	1.55	2.90	3.65	1.50	1.40	1.00	1.20	1.50	1.70	1.70
18	1.40	1.40	1.55	3.00	3.60	1.50	1.40	1.00	1.30	1.50	1.70	1.70
19	1.40	1.40	1.55	3.15	3.60	1.50	1.40	1.00	1.30	1.50	1.70	1.70
20	1.40	1.55	1.60	3.35	3.60	1.50	1.40	1.00	1.30	1.50	1.70	1.70
21	1.40	1.65	1.60	3.65	3.45	1.70	1.40	1.00	1.30	1.50	1.70	1.70
22	1.40	1.75	1.60	3.80	3.40	2.10	1.40	1.00	1.30	1.50	1.70	1.70
23	1.40	1.80	1.60	3.75	3.25	2.50	1.40	1.00	1.30	1.60	1.70	1.70
24	1.40	1.80	1.60	3.70	3.15	2.80	1.40	1.00	1.30	1.60	1.70	1.70
25	1.40	1.80	1.60	3.70	3.00	2.80	1.40	1.00	1.30	1.60	1.70	1.70
26	1.40	1.80	1.60	3.70	2.95	2.45	1.30	1.00	1.30	1.60	1.70	1.70
27	1.40	1.80	1.60	3.70	2.80	2.40	1.30	1.00	1.30	1.60	1.80	1.70
28	1.40	1.80	1.60	3.70	2.70	2.40	1.30	1.00	1.30	1.60	1.90	1.70
29	1.40	.....	1.60	3.70	2.70	2.25	1.30	1.10	1.30	1.60	2.10	1.70
30	1.40	.....	1.65	3.70	2.65	2.00	1.30	1.10	1.30	1.70	2.00	1.70
31	1.40	.....	1.70	.....	2.55	.....	1.20	1.10	.....	1.70	.....	1.70

Daily gage height, in feet, of Provo River at Provo, Utah, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	4.30	4.20	4.40	4.40	5.20	5.40	4.20	3.80	3.80	3.80	4.10	4.20
2	4.30	4.20	4.40	4.40	5.20	5.50	4.20	3.80	3.80	3.80	4.10	4.20
3	4.30	4.20	4.40	4.40	5.10	5.50	4.00	3.80	3.80	3.80	4.10	4.20
4	4.30	4.20	4.40	4.40	5.10	5.50	4.00	3.80	3.80	3.80	4.10	4.20
5	4.30	4.20	4.40	4.40	5.00	5.30	4.00	3.80	3.80	3.80	4.10	4.20
6	4.30	4.20	4.40	4.40	5.00	5.20	4.00	3.80	3.80	3.80	4.20	4.20
7	4.30	4.20	4.40	4.40	5.00	5.20	4.00	3.80	3.80	3.80	4.20	4.20
8	4.30	4.20	4.40	4.40	5.10	5.20	4.00	3.80	3.80	3.80	4.20	4.20
9	4.10	4.20	4.40	4.40	5.10	5.20	4.00	3.80	3.80	3.80	4.20	4.20
10	4.10	4.20	4.40	4.40	5.10	5.00	4.00	3.80	3.80	3.80	4.20	4.20
11	4.10	4.20	4.40	4.50	5.10	5.00	4.00	3.80	3.80	3.80	4.20	4.20
12	4.10	4.20	4.40	4.50	5.20	5.10	4.00	3.80	3.80	3.80	4.20	4.20
13	4.10	4.20	4.40	4.60	5.20	5.20	4.00	3.80	3.80	3.80	4.20	4.20
14	4.10	4.20	4.40	4.60	5.20	5.40	4.00	3.80	3.80	3.80	4.20	4.20
15	4.10	4.20	4.40	4.60	5.20	5.40	4.00	3.80	3.80	3.80	4.20	4.20
16	4.10	4.20	4.40	4.70	5.20	5.40	4.00	3.80	3.80	4.10	4.20	4.20
17	4.10	4.20	4.40	4.60	5.20	5.10	3.90	3.80	3.80	4.10	4.20	4.20
18	4.10	4.20	4.40	4.70	5.20	5.00	3.90	3.80	3.80	4.10	4.20	4.10
19	4.10	4.20	4.40	4.80	5.20	4.70	3.90	3.80	3.80	4.10	4.20	4.10
20	4.10	4.20	4.40	4.90	5.20	4.70	3.90	3.80	3.80	4.10	4.20	4.10
21	4.10	4.20	4.40	4.60	5.20	4.70	3.90	3.80	3.80	4.10	4.20	4.10
22	4.10	4.20	4.40	4.60	5.10	4.90	3.90	3.70	3.80	4.10	4.20	4.10
23	4.20	4.30	4.40	4.70	5.00	4.80	3.90	3.70	3.80	4.10	4.20	4.10
24	4.20	4.40	4.40	4.80	5.40	4.70	3.80	3.70	3.80	4.10	4.20	4.10
25	4.20	4.40	4.40	4.90	5.40	4.70	3.80	3.70	3.80	4.10	4.20	4.20
26	4.20	4.40	4.40	5.10	5.30	4.60	3.80	3.70	3.80	4.10	4.20	4.20
27	4.20	4.40	4.40	5.10	5.20	4.60	3.80	3.70	3.80	4.10	4.20	4.20
28	4.20	4.40	4.40	5.10	5.20	4.40	3.80	3.70	3.80	4.10	4.20	4.20
29	4.20	.....	4.40	5.20	5.30	4.40	3.80	3.80	3.80	4.10	4.20	4.20
30	4.20	.....	4.40	5.20	5.30	4.20	3.80	3.80	3.80	4.10	4.20	4.20
31	4.20	.....	4.40	.....	5.40	.....	3.80	3.80	.....	4.10	.....	4.20

Daily gage height, in feet, of Utah Lake at Geneva, Utah, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	.....	1.40	1.40	.....	.....	2.00	.....	1.00	.....	.....	0.75	.....
2	.....	.....	.....	.....	1.50	.....	1.65	.....	.....	.....	.....	.....
3	1.00	1.40	1.45	.....	.....	.....	.....	.....	0.20	0.65	.75	.....
4	.....	.....	.....	1.55	1.70	2.00	1.60	.90	.....	.....	.....	.....
5	1.05	1.45	1.50	.....	.....	.....	.....	.....	.25	.....	.75	0.55
6	.....	.....	.....	1.50	.....	2.10	.....	.90	.....	.65	.....	.....
7	.....	1.40	1.50	.....	1.65	.....	1.60	.....	.25	.....	.75	.55
8	1.10	.....	.....	.....	.....	2.00	.....	.90	.....	.65	.....	.....
9	.....	1.35	1.50	1.50	1.70	.....	1.55	.....	.....	.....	.....	.....
10	1.10	.....	.....	.....	.....	.....	.....	.80	.40	.65	.75	.55
11	.....	.....	.....	1.45	1.70	1.95	1.55	.....	.....	.....	.....	.....
12	1.10	1.30	1.50	.....	.....	.....	.....	.....	.45	.70	.70	.....
13	.....	.....	.....	.....	.....	2.00	.....	.75	.....	.....	.....	.....
14	.....	1.30	1.50	1.45	1.70	.....	1.55	.....	.....	.....	.70	.....
15	1.15	.....	.....	.....	.....	.....	.....	.80	.40	.70	.....	.....
16	.....	.....	1.50	1.45	1.70	2.00	1.40	.....	.....	.....	.....	.55
17	1.20	1.30	.....	.....	.....	.....	.....	.....	.45	.....	.75	.55
18	.....	.....	.....	1.40	1.75	1.80	1.60	.....	.....	.70	.....	.....
19	.....	1.30	1.55	.....	.....	.....	.....	.....	.45	.....	.80	.50
20	1.25	.....	.....	.....	.....	1.90	.....	.....	.....	.65	.....	.....
21	.....	1.35	1.55	1.40	1.80	.....	1.25	.....	.....	.....	.....	.....
22	1.30	.....	.....	.....	.....	1.90	.....	.....	.50	.70	.....	.....
23	.....	1.35	1.55	1.40	1.90	.....	1.20	.....	.....	.....	.....	.....
24	1.30	.....	.....	.....	.....	.....	.....	.....	.55	.75	.70	.45
25	.....	.....	.....	1.40	.....	1.85	1.15	.50	.....	.....	.....	.....
26	1.35	1.40	1.55	.....	1.95	.....	.....	.50	.60	.....	.75	.40
27	.....	.....	.....	1.40	.....	1.80	.....	.50	.....	.70	.....	.....
28	.....	.....	1.55	.....	2.00	.....	1.10	.....	.....	.....	.65	.....
29	1.35	.....	.....	.....	.....	1.80	.....	.....	.65	.75	.....	.....
30	.....	.....	.....	1.40	2.00	.....	1.10	.....	.65	.....	.60	.....
31	.....	.....	1.55	.....	.....	.....	.....	.....	.....	.....	.....	.40

List of discharge measurements, 1898.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
				Feet.	*Sec.-feet.*
Mar. 25	North Fork of Humboldt River.	Peko, Nev	L. H. Taylor	2.65	43
Apr. 30	do	do	do	3.20	129
June 26	do	do	do	2.90	71
July 21	do	do	do	1.80	6
Sept. 20	do	do	do	1.45	.3
Feb. 26	Humboldt River	Elko, Nev	do	4.08	423
Mar. 26	do	do	do	2.80	140
Apr. 30	do	do	do	3.40	271
June 26	do	do	do	3.60	316
July 21	do	do	do	2.10	44
Sept. 19	do	do	do	1.70	1
Feb. 28	do	Golconda, Nev	do	4.20	436
Apr. 10	do	do	do	2.90	239
Apr. 18	do	do	do	2.40	169
May 10	do	do	do	.95	24
June 4	do	do	do	3.70	341
July 23	do	do	do	1.50	70
Sept. 25	do	do	do	0.00	.2
Mar. 31	do	Oreana, Nev	do	3.30	324
Apr. 11	do	do	do	2.85	193
May 14	do	do	do	1.50	43
June 9	do	do	do	1.25	21
June 19	do	do	do	1.41	38
Feb. 27	South Fork of Humboldt River.	Masons Ranch, Nev.	do	1.55	159
Apr. 29	do	do	do	2.05	275
June 25	do	do	do	2.30	313
July 22	do	do	do	.85	52
Sept. 19	do	do	do	.35	.7
June 12	Bear River	Soda Springs, Idaho.	F. J. Mills	6.60	2,049
Aug. 25	do	do	C. C. Babb	5.00	290
Oct. 8	do	do	F. S. Shirley	5.15	519
Apr. 30	do	Battle Creek, Idaho.	J. S. Baker	3.65	3,016
May 23	do	do	do	3.40	2,594
June 20	do	do	do	2.98	1,997
Aug. 4	do	do	do	1.45	592
Aug. 24	do	do	do	1.38	508
Do.	do	do	do	1.38	539
Nov. 29	do	do	do	1.67	673
Apr. 11	Logan River	Logan, Utah	do	2.75	229
Apr. 14	do	do	do	2.88	281
May 2	do	do	do	3.35	474
May 9	do	do	do	3.35	475
May 16	do	do	do	3.65	652
May 31	do	do	do	3.75	690
June 10	do	do	do	3.75	723
June 18	do	do	do	3.72	663
Aug. 4	do	do	do	2.82	233
Aug. 24	do	do	do	2.85	204
Do.	do	do	do	2.85	210
Nov. 30	do	do	do	2.57	155
Apr. 16	Bear River	Collinston, Utah	S. Fortier	4.18	4,797
June 17	do	do	J. L. Rhead	3.27	3,419
June 20	do	do	do	3.04	3,136
June 21	do	do	J. S. Baker	3.06	2,724
July 30	do	do	J. L. Rhead	1.20	809
Aug. 19	do	do	do	1.13	732
Sept. 30	do	do	do	1.35	852
June 23	Ogden River	Ogden, Utah	J. S. Baker	2.11	134
Aug. 26	do	do	do	1.45	27
Sept. 10	do	do	do	1.45	36
June 24	Weber River	Uinta, Utah	do	2.90	1,327
Aug. 31	do	do	do	1.05	104
Sept. 3	do	do	do	1.05	104
Sept. 6	do	do	do	1.10	125
May 23	Provo River	Provo, Utah	W. B. Dougall	4.85	704
June 6	do	do	do	5.20	938
Sept. 15	do	do	do	3.85	192

the head waters serve as reservoirs, giving the stream a relatively constant flow. The economic importance of the river is great on account of its rapid fall, the volume of water discharged, and its purity. The principal industrial applications are found near the mouth of the river, where power can be obtained and water used upon adjacent lands for irrigation. The measurements, therefore, at Bonner are particularly valuable. The conditions are favorable for accurate measurement, except for the fact that the height of water is influenced by a dam of the Big Blackfoot Milling Company, located about 1,000 yards above, furnishing water for mills and electric-power stations. The opening and closing of the flood gates of the dam causes abrupt changes in the flow of the stream.

Missoula station on Bitterroot River.—This station is on the Buckhouse wagon bridge, on the main road, 6 miles southwest of Missoula. It was established by Mr. Cyrus C. Babb, and observations were begun on July 6, 1898. The observer is Joe Buckhouse, a farmer living one-half mile from the bridge. Observations are made at 7 a. m. A wire gage is used, with a 5-pound sash weight. The length of the gage wire is 22.83 feet, and the pulley distance—that is, the distance from the zero of the gage to the outside edge of the pulley—is 0.50 feet. A bench mark has been established by the topographers. This consists of a nail in the base of the Northern Pacific Railway sign crossing, 120 feet from the west end of the bridge. This nail is at an elevation of 3,127.6 feet above sea level. It is about 20 feet above the floor of the bridge. The initial point for soundings is directly over the inside edge of the cylindrical casement of the abutment of the bridge, on the upper side at the left hand end. The channel is nearly straight; the right bank low and liable to overflow, the left bank high and rocky. The bed of the stream is of gravel, in which an old pier of a former bridge remains near the center of the stream, causing annoyance in measurements when the water is high. The results obtained at the Buckhouse Bridge, which is near the mouth of the river, are of value mainly in giving the total discharge of the stream. On account of the slight fall water can not be diverted for irrigation for a distance of 25 miles or more above this locality. At a point 10 miles above the station the river is 4 feet lower than the valley around Missoula. The total fall from Hamilton to Missoula, a distance of 48 miles, is about 350 feet. The measurements have a high degree of accuracy since the stream is deep, the current relatively slow, and the fluctuations in height are gradual.

Missoula station on Missoula River.—This station is located at the Higgins Avenue Bridge in Missoula, across the river of that name. It was originally established by Mr. Cyrus C. Babb, and observations were begun on July 10, 1898. The observer is E. S. Newton, a carpenter, whose workshop is on the bank of the river. Observations are made at 7 a. m. and 6 p. m. The gage consists of two rods, one fastened to a pile, the other to planking on one of the piers at the north end

of the bridge. The elevation of the zero is 3,156 feet above sea level, as verified by the topographers of the United States Geological Survey. Bench mark No. 1 consists of a nail in the top of a 10-inch by 10-inch post of the old bridge, 2.5 feet above ground and 36 feet northwestward of the rod, its elevation being 3,170.25 feet above sea level, or 14.25 feet above the zero of the rod. The second bench mark consists of a nail in the piling of the bridge to which the gage rod is fastened; it is opposite the 8-foot mark. On August 10 the gage on the pile at the north end of the bridge was out of water, and the second rod was nailed to the pier of the bridge, about 20 feet from the first. All graduations on the first rod and all gage-height readings have been changed to conform to the second rod.

Soundings and discharge measurements are taken from the railroad bridge, about a mile below. The channel is nearly straight, the banks high, and the bed rocky. During high water the left bank is flooded for some distance above the bridge, and a second stream crosses the bars some 400 feet south of the main channel of the stream. The initial point for soundings is on the right end of the bridge at the edge of the abutment.

Missoula River is one of the most important rivers west of the Rocky Mountains. Its drainage area, including that of Blackfoot River, is 5,960 square miles. In its course to the Columbia the stream bears various names, being locally known as the Hellgate, the Missoula, and finally Clarkes Fork of the Columbia. Where measured at Missoula the flow includes that of the Hellgate and Blackfoot rivers. There is a large extent of arable land along the river at and below Missoula to which water may be brought from this stream. The rapid fall will make the river valuable as a source of power wherever suitable dams can be built. The slimes and tailings from the ore concentrators at Butte and Anaconda render the water turbid and unfit for drinking.

It is proposed to construct a dam across the river 2 miles above Missoula for the diversion of water into a large canal covering portions of the Missoula and Grass valleys, within which are thousands of acres of nearly level land at present unproductive from lack of water. By the construction of such a dam sufficient power can probably be obtained to generate electricity for local needs. Measurements made at Missoula give fairly accurate results and are of considerable importance in discussing projects of this nature.

Lakeside station on Lake Chelan.—A gage on this lake was established by Capt. Charles Johnson at the base of the rock pier on the lake shore north of his house and about one-half mile from the steamboat landing at Lakeside. This consists of a timber 2 inches square and 8 feet high, marked to feet and tenths. Observations were maintained from September 1 to October 15, 1897, at which time they were discontinued until January 1, 1898. This gage is located about 400 feet northwest from the permanent bench mark established by Mr. William

T. Griswold in 1897, consisting of the usual iron post with brass cap, the elevation stamped on the top being 1,121 feet above sea level. The iron post is on the west line of East Center street in the town of Lakeside. In the readings given on page 164 the figures 1,100 should be added to give the elevation above tide.

Capt. Charles Johnson, of Lakeside, Washington, writes concerning Lake Chelan as follows:

> This lake is fed by mountain streams which have their sources in the glaciers of the Cascade Mountains, furnishing the lake with water as pure as crystal. The Stehekin River, the main tributary of the lake, finds its source on the very summit of the Cascades in glaciers of great extent and magnificence. The foot of the lake is 3 miles from Columbia River, at an elevation of 360 feet above the river, into which the waters flow through Chelan River. From the foot the lake extends in a northwest direction, penetrating the Cascade Mountains almost to their center, affording a panorama of majestic scenery that is rarely found on the shores of any lake.
>
> At the foot of the lake, and for 25 miles up, it is surrounded with low foothills and good soil, well adapted to farming and horticulture. From thence the mountains rise higher and higher, with almost perpendicular granite walls, until at the head of the lake the mountain peaks stand 8,000 to 10,000 feet above sea level. The lake has now four steamers plying its waters, supplying the many mining camps in the uplake region and affording accommodations to tourists and pleasure seekers. The lake is open to navigation for the whole year. This is due to the great depth of the lake and the mild temperature of the region. The average winter temperature is about 27° to 28° F.

North Yakima station on Naches River.—This station, originally established August 14, 1893, and abandoned in February, 1897, was reestablished on February 1, 1898; and the station at Selah, on the Yakima River, described in the Nineteenth Annual Report, Part IV, pages 477–479, 5 miles above the mouth of the Naches, was discontinued. The observer is Pat. Gallagher, section foreman. Since the reestablishment of the Naches station the river channel has been in a condition more favorable for meter observations than formerly. Discharge measurements are made from the lower side of the highway bridge. A new horizontal gage rod, with wire and weight, has been attached to the main span of the Northern Pacific Railway bridge at the mouth of the Naches, a few hundred feet downstream from the highway bridge. The length of the gage wire from index to foot of weight is 30.41 feet. The pulley distance is 5.844 feet. The elevation of top of pulley is 24.57 feet. The bench mark is the top of the north end of east sill of clearance posts, about 150 feet north of Northern Pacific Railway bridge. Elevation, 23.766 feet. On December 27, 1898, Mr. Arnold connected the highway bridge with this bench mark. The top of the northeast concrete pier was found to be at an elevation of 22.09 feet, and the top of the bridge post at the 150-foot mark, at an elevation of 26.76 feet. The distance from top of post to surface of water has been carefully measured at each discharge measurement, so that the exact river height at the highway bridge is known.

Union Gap station on Yakima River.—Described on page 175 of Paper No. 16; results for 1897 given on pages 479–481 of the Nineteenth Annual Report, Part IV. The old bench mark having been obliterated, a new one has been set. It is the highest point of a large rock mound, 25 feet north of gage and 10 feet east of fence; elevation, 17.52 above zero of gage rod.

Kiona station on Yakima River.—Described on page 176 of Paper No. 17; results for 1897 given on pages 482–486 of the Nineteenth Annual Report, Part IV.

Spokane station on Spokane River.—Described on page 177 of Paper No. 16; results for 1897 given on pages 487–489 of the Nineteenth Annual Report, Part IV.

Whitman station on Wallawalla River.—Described on page 179 of Paper No. 16; results for 1898 given on pages 490–492 of the Nineteenth Annual Report, Part IV.

Gibbon station on Umatilla River.—Described on page 180 of Paper No. 16; results for 1897 given on pages 493, 494 of the Nineteenth Annual Report, Part IV.

Moro station on Deschutes River.—Described on page 181 of Paper No. 16. A measurement was made in 1898 by Sydney Arnold. No rating table was constructed, for lack of sufficient data.

Tucker station on Hood River.—Described on page 181 of Paper No. 16; results for 1897 given on pages 498–500 of the Nineteenth Annual Report, Part IV.

TABLES OF DAILY GAGE HEIGHT.

Daily gage height, in feet, of Portneuf River at Pocatella, Idaho, for 1898.

Day.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	.....	7.60	7.30	7.40	6.90	6.60	6.70	6.80	7.10	7.10
2	.....	7.60	7.20	7.50	7.00	6.60	6.65	6.80	7.10	7.10
3	.....	7.70	7.20	7.60	7.00	6.60	6.65	6.80	7.10	7.10
4	.....	7.80	7.20	7.60	6.10	6.60	6.65	6.80	7.10	7.20
5	.....	7.80	7.20	7.60	6.10	6.60	6.65	6.85	7.20	7.20
6	.....	7.80	7.20	7.60	6.10	6.60	6.60	6.85	7.20	7.20
7	.....	8.00	7.30	7.70	6.10	6.60	6.65	6.90	7.20	7.20
8	.....	8.00	7.30	7.90	6.10	6.70	6.70	6.90	7.20	7.20
9	.....	8.00	7.30	7.90	6.10	6.70	6.70	6.90	7.20	7.20
10	.....	8.00	7.30	7.90	6.10	6.70	6.65	6.90	7.10	7.20
11	.....	7.90	7.40	8.00	6.10	6.60	6.65	6.90	7.10	7.20
12	.....	7.80	7.40	7.10	6.20	6.70	6.70	6.90	7.10	7.30
13	.....	7.80	7.40	7.20	6.10	6.70	6.70	6.90	7.10	7.20
14	.....	7.70	7.40	7.30	7.10	6.70	6.70	6.90	7.10	7.10
15	.....	7.60	7.40	7.40	7.00	6.70	6.70	6.90	7.20	7.20
16	6.15	7.50	7.40	7.40	7.10	6.70	6.70	6.90	7.20	7.20
17	.....	7.40	7.40	7.40	6.10	6.60	6.70	6.90	7.20	7.20
18	.....	7.40	7.40	7.50	6.10	6.60	6.70	6.90	7.20	7.20
19	.....	7.40	7.30	7.40	6.20	6.70	6.65	6.90	7.30	7.30
20	.....	7.40	7.20	7.40	6.20	6.60	6.70	6.90	7.30	7.30
21	.....	7.40	7.20	7.30	6.30	6.70	6.70	6.90	7.20	7.40
22	.....	7.30	7.20	7.30	6.20	6.70	6.80	6.90	7.20	7.40
23	.....	7.20	7.30	7.20	6.20	6.65	6.80	7.00	7.20	7.50
24	.....	7.20	7.30	7.20	6.20	6.60	6.80	7.10	7.20	7.60
25	.....	7.20	7.30	7.20	6.20	6.60	6.80	7.20	7.20	7.60
26	.....	7.20	7.40	7.10	6.20	6.60	6.80	7.20	7.20	7.60
27	7.60	7.10	7.30	7.10	6.20	6.60	6.80	7.20	7.20	7.60
28	7.40	7.10	7.40	7.00	6.20	6.70	6.80	7.20	7.20	7.60
29	7.40	7.10	7.30	7.00	6.30	6.70	6.80	7.10	7.10	7.60
30	7.60	7.20	7.30	7.00	6.40	6.75	6.80	7.10	7.10	7.60
31	7.50	.....	7.40	.....	6.70	6.70	.....	7.20	.....	7.60

Daily gage height, in feet, of Snake River at Montgomery, Idaho, for 1898.

Day.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	.....	2.90	6.85	8.20	6.30	2.80	1.90	2.20	2.80	2.90
2	.....	2.90	6.60	8.15	5.95	2.70	2.00	2.20	2.80	3.00
3	.....	2.90	6.30	7.75	5.70	2.60	2.10	2.30	2.80	3.00
4	.....	2.90	6.20	7.45	5.35	2.60	2.15	2.30	2.80	3.00
5	.....	2.90	6.25	7.25	5.25	2.55	2.20	2.30	2.80	2.90
6	.....	2.90	6.00	7.15	5.05	2.45	2.20	2.30	2.80	2.65
7	.....	2.90	5.70	6.95	4.90	2.35	2.20	2.30	2.80	3.80
8	.....	2.90	5.45	6.70	4.80	2.30	2.20	2.35	2.80	4.70
9	.....	2.90	5.40	6.35	4.75	2.20	2.20	2.40	2.80	4.45
10	.....	2.90	5.40	6.10	4.65	2.20	2.30	2.40	2.80	4.10
11	.....	3.00	5.40	5.90	4.50	2.10	2.30	2.40	2.80	3.75
12	.....	3.00	5.45	5.85	4.50	2.05	2.30	2.40	2.80	3.30
13	3.20	3.00	5.55	5.90	4.45	2.00	2.30	2.40	2.80	2.90
14	3.20	3.15	5.75	6.00	4.65	2.00	2.30	2.40	2.80	2.65
15	3.10	3.25	5.95	6.30	4.75	1.90	2.30	2.40	2.80	2.60
16	3.10	3.60	6.15	6.65	4.75	1.90	2.30	2.50	2.80	2.60
17	3.10	3.85	6.30	6.85	4.60	1.90	2.30	2.50	2.80	2.70
18	3.00	4.10	6.45	7.05	4.45	1.90	2.30	2.60	2.90	2.80
19	3.00	4.50	6.65	7.25	4.40	1.90	2.20	2.60	2.90	2.90
20	3.00	4.80	6.80	7.45	4.35	1.90	2.20	2.60	2.90	3.00
21	3.00	4.90	6.90	7.60	4.20	1.90	2.20	2.60	3.00	3.05
22	3.00	4.90	7.00	7.75	4.00	1.90	2.20	2.65	3.00	3.20
23	2.90	4.90	6.85	7.90	3.80	1.90	2.20	2.70	3.00	3.20
24	2.80	5.05	6.65	7.80	3.65	1.90	2.20	2.70	3.00	3.10
25	2.70	5.25	6.45	7.70	3.45	1.90	2.20	2.70	2.95	3.00
26	2.80	5.50	6.45	7.65	3.35	1.90	2.20	2.80	2.85	3.10
27	2.90	5.80	6.80	7.55	3.25	1.90	2.20	2.80	2.80	3.20
28	2.90	6.20	7.20	7.30	3.20	1.90	2.20	2.80	2.80	3.25
29	2.90	6.50	7.45	7.00	3.10	1.90	2.20	2.80	2.85	3.30
30	2.90	6.85	7.65	6.60	3.00	1.90	2.20	2.80	2.90	3.35
31	2.90	.....	8.00	.....	2.90	1.90	.....	2.80	.....	3.30

Daily gage height, in feet, of Little Wood River at Toponis, Idaho, for 1898.

y.	Mar.	Apr.	Day.	Mar.	Apr.	Day.	Mar.	Apr.	Day.	Mar.	Apr.
1	.....	3.90	9	.....	.....	17	4.20	.....	25	3.90	.....
2	.....	3.90	10	.....	.....	18	4.20	.....	26	3.80	.....
3	.....	3.90	11	.....	.....	19	4.00	.....	27	3.90	.....
4	.....	3.90	12	.....	.....	20	4.00	.....	28	3.90	.....
5	.....	4.10	13	.....	.....	21	4.00	.....	29	3.90	.....
6	.....	4.10	14	.....	.....	22	4.00	.....	30	3.90	.....
7	.....	.....	15	.....	.....	23	4.00	.....	31	3.90	.....
8	.....	.....	16	.....	.....	24	4.00	.....			

Daily gage height, in feet, of Malad River at Toponis, Idaho, for 1898.

Day.	Mar.	Apr.	May.	June	July.	Aug.	Day.	Mar.	Apr.	May.	June	July.	Aug.
1	.....	2.70	4.00	3.90	4.80	1.50	17	2.80	3.90	3.60	4.20	3.00	.....
2	.....	2.70	4.00	4.10	4.80	1.40	18	2.80	3.90	3.60	4.30	3.00	.....
3	.....	2.70	4.00	4.30	4.00	1.40	19	2.70	4.00	3.60	4.60	3.00	.....
4	.....	2.70	4.00	4.40	4.00	1.30	20	2.70	4.20	3.60	4.50	3.00	.....
5	.....	2.70	4.00	4.60	3.90	1.00	21	2.70	4.20	3.60	4.10	2.80	.....
6	.....	2.60	3.80	4.80	3.70	1.00	22	2.70	4.20	3.60	4.30	2.70	.....
7	.....	2.60	3.60	4.50	3.50	.....	23	2.70	4.10	3.70	4.40	2.50	.....
8	.....	2.60	3.40	4.30	3.40	.....	24	2.70	4.20	3.80	4.80	2.40	.....
9	.....	2.60	3.50	4.20	3.30	.....	25	2.70	4.00	3.90	4.40	2.40	.....
10	.....	2.70	3.20	4.00	3.30	.....	26	2.70	4.60	3.90	4.40	2.40	.....
11	.....	3.00	3.40	4.00	3.20	.....	27	2.70	4.20	3.70	4.40	2.00	.....
12	.....	3.60	3.20	4.10	3.20	.....	28	2.70	4.00	3.70	4.40	2.00	.....
13	2.80	3.90	3.40	4.20	3.10	.....	29	2.70	4.00	3.80	4.70	2.00	.....
14	2.80	4.00	3.50	4.20	3.10	.....	30	2.70	4.00	3.90	4.90	1.80	.....
15	2.80	4.00	3.60	4.30	3.00	.....	31	2.70	.....	3.90	.....	1.70	.....
16	2.80	3.90	3.60	4.30	3.00	.....							

Daily gage height, in feet, of Bruneau River at Grandview, Idaho, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	1.65	1.55	2.20	1.85	3.10	2.75	1.95	1.15	1.10	1.20	1.40	1.70
2	1.65	1.60	2.40	1.85	3.00	2.70	1.95	1.15	1.10	1.20	1.40	1.75
3	1.65	1.65	2.30	1.90	3.00	2.65	1.90	1.15	1.10	1.20	1.45	1.70
4	1.60	1.65	2.10	2.00	2.95	2.65	1.80	1.15	1.10	1.20	1.45	1.70
5	1.60	1.65	2.10	2.10	2.95	2.65	1.80	1.15	1.10	1.30	1.45	1.65
6	1.65	1.70	2.15	2.00	2.80	2.60	1.80	1.15	1.10	1.30	1.45	1.60
7	1.65	1.75	2.25	2.30	2.75	2.50	1.80	1.15	1.10	1.30	1.45	1.60
8	1.65	1.75	2.30	2.50	2.70	2.45	1.75	1.15	1.10	1.30	1.40	1.50
9	1.65	1.75	2.40	2.35	2.65	2.50	1.75	1.15	1.10	1.25	1.40	1.40
10	1.65	1.75	2.50	2.40	2.65	2.60	1.70	1.10	1.10	1.30	1.40	1.40
11	1.65	1.70	2.30	2.90	2.70	2.60	1.75	1.10	1.10	1.35	1.40	1.35
12	1.50	1.75	2.10	3.10	2.80	2.60	1.70	1.10	1.10	1.35	1.40	1.35
13	1.40	1.80	2.00	3.10	2.85	2.60	1.70	1.10	1.05	1.35	1.40	1.30
14	1.45	1.95	2.00	3.15	2.90	2.70	1.65	1.10	1.05	1.35	1.40	1.30
15	1.45	2.00	1.95	3.25	3.00	2.75	1.65	1.10	1.05	1.35	1.40	1.30
16	1.50	3.20	1.95	3.30	3.05	2.70	1.60	1.10	1.05	1.35	1.40	1.30
17	1.80	3.20	1.90	3.35	3.00	2.75	1.55	1.10	1.05	1.35	1.45	1.35
18	1.80	2.55	1.85	3.30	3.00	2.80	1.55	1.10	1.05	1.35	1.55	1.35
19	1.80	2.10	1.85	3.30	3.10	2.80	1.50	1.10	1.05	1.35	1.55	1.40
20	1.80	2.10	1.90	3.20	3.00	2.80	1.50	1.10	1.05	1.35	1.60	1.40
21	1.80	2.00	1.90	3.15	3.00	2.70	1.55	1.10	1.05	1.35	1.60	1.50
22	1.75	1.95	1.85	3.20	2.85	2.60	1.45	1.10	1.05	1.40	1.55	1.50
23	1.75	1.90	1.80	3.20	2.80	2.50	1.30	1.10	1.05	1.40	1.50	1.50
24	1.70	1.90	1.80	3.15	2.80	2.40	1.30	1.10	1.05	1.40	1.50	1.50
25	1.60	1.85	1.80	3.15	2.75	2.35	1.30	1.10	1.10	1.45	1.50	1.40
26	1.60	1.85	1.85	3.15	2.75	2.30	1.25	1.10	1.10	1.50	1.50	1.45
27	1.50	2.00	1.90	3.25	2.75	2.20	1.25	1.10	1.10	1.50	1.45	1.45
28	1.50	2.00	1.80	3.30	2.80	2.10	1.25	1.10	1.10	1.40	1.50	1.50
29	1.50	.....	1.80	3.20	3.00	2.00	1.25	1.10	1.10	1.40	1.60	1.50
30	1.50	.....	1.85	3.20	3.00	2.00	1.25	1.10	1.10	1.40	1.70	1.50
31	1.50	.....	1.90	.....	2.80	.....	1.20	1.10	.....	1.40	.....	1.50

Daily gage height, in feet, of Boise River at Boise, Idaho, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	.....	.....	1.70	1.60	4.30	3.55	2.60	1.20	1.00	1.00	1.25	1.30
2	.....	.....	1.80	1.70	4.20	3.50	2.50	1.30	1.00	1.05	1.25	1.30
3	1.00	1.00	1.80	1.70	4.20	3.50	2.20	1.20	1.05	1.10	1.30	1.30
4	.....	.....	1.80	1.50	3.90	3.30	2.20	1.20	1.05	1.10	1.30	1.30
5	.....	.....	2.00	1.40	3.40	3.20	2.10	1.20	1.05	1.10	1.25	1.60
6	1.00	.....	2.10	1.50	3.20	3.90	2.20	1.20	1.05	1.10	1.25	1.80
7	.....	1.00	2.10	1.70	3.30	3.10	2.10	1.20	1.05	1.10	1.25	2.00
8	.....	.....	2.00	1.60	3.30	3.00	2.10	1.20	1.05	1.10	1.25	2.30
9	.....	.....	2.00	1.60	3.30	3.10	2.20	1.20	1.05	1.10	1.25	2.20
10	1.00	1.30	2.10	1.90	3.50	3.40	2.20	1.20	1.10	1.20	1.25	2.20
11	.....	.....	2.30	2.00	3.50	3.55	2.10	1.20	1.10	1.25	1.25	2.20
12	.....	.....	2.20	2.20	3.50	3.70	2.20	1.15	1.10	1.20	1.10	2.20
13	1.00	.....	2.10	2.90	3.90	3.90	2.00	1.15	1.10	1.20	1.10	2.20
14	.....	1.40	1.80	3.70	3.90	4.00	2.00	1.15	1.10	1.25	1.10	2.10
15	.....	.....	1.90	3.90	4.00	4.20	1.90	1.10	1.10	1.20	1.10	2.10
16	.....	.....	1.80	4.20	3.95	4.20	1.80	1.10	1.10	1.20	1.10	2.30
17	1.00	1.70	1.70	4.40	3.95	4.20	1.70	1.00	1.10	1.20	1.20	2.30
18	.....	.....	1.70	4.40	3.60	4.10	1.65	1.00	1.05	1.20	1.35	2.30
19	.....	.....	1.70	3.90	3.50	4.10	1.60	1.10	1.00	1.20	1.30	2.30
20	1.00	.....	1.70	3.90	3.60	4.00	1.55	1.10	1.00	1.20	1.35	2.30
21	.....	1.50	1.80	4.00	3.60	4.00	1.50	1.10	1.00	1.20	1.30	2.30
22	.....	.....	1.70	4.00	3.55	4.00	1.45	1.10	1.00	1.20	1.30	2.20
23	.....	.....	1.60	4.00	3.55	4.00	1.40	1.00	1.10	1.25	1.20	2.20
24	1.00	.....	1.50	4.00	3.55	3.90	1.35	1.00	1.05	1.25	1.20	2.20
25	.....	1.50	1.50	4.10	3.55	3.70	1.30	1.00	1.10	1.20	1.20	2.20
26	.....	.....	1.50	4.50	3.60	3.40	1.25	1.00	1.05	1.20	1.20	2.40
27	1.00	.....	1.50	4.50	3.60	3.40	1.20	1.00	1.05	1.25	1.20	2.60
28	.....	1.70	1.50	4.50	3.65	3.00	1.20	1.00	1.05	1.25	1.20	2.60
29	.....	.....	1.60	4.40	4.30	2.90	1.20	1.00	1.10	1.25	1.20	2.40
30	1.00	.....	1.70	4.30	4.00	2.70	1.25	1.05	1.10	1.25	1.25	2.40
31	1.00	.....	1.70	.....	3.75	.....	1.20	1.00	.....	1.25	.....	2.30

Daily gage height, in feet, of Weiser River at Weiser, Idaho, for 1898.

Day.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	.....	0.80	3.60	3.20	1.90	0.70	0.60	0.60	0.85	0.95
2	.....	.90	3.50	3.20	1.90	.60	.60	.60	.85	.95
3	.....	.90	3.40	3.20	1.80	.60	.60	.65	.85	1.20
4	.....	.90	3.30	3.10	1.80	.60	.65	.65	.85	1.95
5	.....	2.00	3.20	3.00	1.70	.50	.60	.70	.85	1.90
6	.....	2.30	3.10	2.90	1.70	.50	.50	.75	.85	2.20
7	.....	2.70	3.10	2.90	1.70	.50	.50	.75	.85	2.30
8	.....	2.70	3.00	2.80	1.60	.50	.50	.80	.85	2.20
9	.....	2.60	3.00	2.80	1.60	.40	.40	.80	.85	2.10
10	.....	2.70	3.00	2.80	1.50	.40	.40	.80	.85	2.00
11	.....	3.10	3.10	2.70	1.50	.40	.40	.80	.90	2.00
12	.....	3.20	3.10	2.70	1.40	.30	.40	.80	.90	2.00
13	2.60	3.30	3.10	2.70	1.40	.30	.40	.80	.90	2.00
14	2.50	3.50	3.10	2.60	1.30	.30	.40	.80	.95	2.00
15	2.40	4.00	3.00	2.60	1.30	.30	.40	.80	.95	2.00
16	2.40	4.30	3.00	2.60	1.20	.30	.40	.80	.95	2.00
17	2.30	4.40	3.00	2.50	1.20	.30	.40	.80	1.10	2.00
18	2.20	4.30	3.00	2.50	1.10	.30	.40	.80	1.00	2.00
19	2.10	3.90	3.00	2.50	1.10	.30	.40	.85	.95	2.00
20	2.00	3.80	2.90	2.40	1.10	.30	.40	.85	.95	2.00
21	1.90	3.70	2.80	2.40	1.00	.20	.40	.85	.95	2.00
22	1.80	3.80	2.80	2.40	1.00	.25	.40	.85	.95	2.00
23	1.70	3.90	2.70	2.30	1.00	.40	.40	.85	.95	2.00
24	1.60	4.00	2.70	2.30	.90	.40	.40	.85	.95	2.00
25	1.50	3.90	2.70	2.30	.90	.40	.40	.85	.95	2.00
26	1.30	4.00	2.80	2.20	.90	.45	.45	.85	.95	2.00
27	1.10	4.40	3.00	2.20	.80	.45	.50	.85	.95	2.00
28	1.00	4.20	3.70	2.10	.80	.50	.50	.85	.95	2.00
29	.90	3.90	3.60	2.10	.80	.50	.60	.85	.95	2.00
30	.80	3.80	3.40	2.00	.70	.50	.60	.85	.95	2.00
31	.80	.....	3.30	.....	.70	.50	.....	.85	.....	2.00

Daily gage height, in feet, of Palouse River at Hooper, Washington, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	7.00	4.20	7.25	6.50	5.65	4.40	2.60	1.95	1.70	1.70	2.10	2.30
2	6.45	4.20	7.35	6.45	5.40	4.20	2.60	1.80	1.70	1.70	2.10	2.35
3	6.05	4.35	7.65	6.33	5.15	4.05	2.60	1.80	1.70	1.70	2.10	2.40
4	5.80	4.50	7.65	6.90	4.95	4.00	2.55	1.65	1.70	1.70	2.05	2.45
5	5.50	4.75	8.15	6.75	4.65	3.90	2.50	1.75	1.65	1.70	2.05	2.80
6	5.50	5.45	8.25	6.88	4.75	3.85	2.50	1.80	1.65	1.75	2.05	2.35
7	5.40	6.20	8.15	7.15	4.90	3.70	2.50	1.80	1.65	1.80	2.05	2.35
8	5.40	7.10	7.85	7.70	4.75	3.65	2.45	1.80	1.70	1.85	2.10	2.30
9	5.25	7.20	7.65	7.85	4.70	3.50	2.45	1.70	1.70	1.85	2.15	2.15
10	4.70	6.40	7.65	7.35	4.50	3.40	2.40	1.70	1.70	1.85	2.20	2.10
11	4.60	5.90	7.35	7.05	4.40	3.30	2.40	1.70	1.70	1.85	2.20	2.05
12	4.70	5.80	7.00	7.25	4.35	3.25	2.35	1.70	1.70	1.85	2.10	2.00
13	4.70	11.00	6.55	7.45	4.30	3.15	2.30	1.65	1.70	1.85	2.10	2.00
14	4.70	12.00	6.40	7.15	4.25	3.10	2.25	1.60	1.70	1.85	2.10	2.00
15	4.70	13.00	6.35	7.10	4.25	3.10	2.20	1.60	1.70	1.80	2.05	2.00
16	4.60	13.99	6.30	7.40	4.20	3.05	2.20	1.65	1.70	1.80	2.05	2.00
17	4.60	13.29	6.30	7.80	4.15	3.05	2.20	1.75	1.70	1.80	2.05	1.95
18	4.70	12.54	6.15	7.75	4.05	3.05	2.20	1.80	1.70	1.80	2.10	2.00
19	4.90	10.84	6.00	7.40	3.95	3.00	2.20	1.90	1.70	1.85	2.15	2.00
20	4.70	9.54	5.90	7.00	3.95	3.00	2.20	1.80	1.70	1.90	2.15	2.15
21	4.50	9.14	5.90	6.53	3.90	3.00	2.20	1.90	1.70	1.85	2.20	2.30
22	4.45	8.85	5.85	6.45	3.85	2.95	2.20	1.70	1.70	1.85	2.35	2.30
23	4.35	8.55	5.45	6.45	3.75	2.90	2.20	1.70	1.70	1.85	2.40	2.30
24	4.00	8.15	5.30	6.55	3.70	2.80	2.20	1.70	1.70	1.85	2.50	2.40
25	4.10	7.95	5.40	6.65	3.65	2.75	2.15	1.70	1.70	2.00	2.45	2.30
26	4.15	7.65	5.55	6.55	3.65	2.75	2.15	1.70	1.70	2.00	2.35	2.35
27	4.15	7.35	5.30	6.30	4.05	2.75	2.10	1.70	1.70	2.05	2.30	2.40
28	4.20	7.25	5.30	6.35	4.05	2.70	2.05	1.70	1.70	2.05	2.20	2.50
29	4.10	.....	5.30	6.40	4.00	2.60	2.05	1.70	1.70	2.05	2.20	2.70
30	4.10	.....	5.40	6.10	4.35	2.60	2.00	1.70	1.70	2.05	2.25	2.90
31	4.25	.....	5.70	.....	4.40	.....	1.95	1.70	.....	2.10	.....	2.70

Daily gage height, in feet, of Blackfoot River at Bonner, Montana, for 1898.

Day.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Day.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	.....	1.80	.95	.90	.85	.80	17	2.75	1.80	.95	.85	.85	.....
2	.....	1.85	1.15	1.10	.85	.80	18	2.65	1.25	.90	.95	.85	.....
3	.....	1.70	1.15	.90	.80	.75	19	2.60	1.30	.95	1.00	.90	.....
4	.....	1.60	1.05	.85	.95	.70	20	2.45	1.30	.90	1.25	.80	.....
5	.....	1.50	1.05	.95	.90	.75	21	2.40	1.25	.90	1.00	.75	.....
6	.....	1.60	1.10	.85	1.25	1.30	22	2.35	1.25	1.00	1.25	.80	.....
7	4.00	1.60	1.05	.70	1.00	.90	23	2.25	1.20	1.05	.85	.75	.....
8	3.65	1.60	1.10	.70	.75	1.40	24	2.25	1.20	1.25	1.25	.80	.....
9	3.50	1.50	1.05	.80	.85	1.40	25	2.20	1.15	1.05	1.20	.85	.....
10	3.45	1.55	1.00	.80	.90	3.40	26	2.15	1.15	1.05	1.40	.85	.....
11	3.35	1.50	.95	.65	.95	(a)	27	2.05	1.20	1.05	1.05	.70	.....
12	3.25	1.70	.95	1.15	.90	(a)	28	1.95	1.20	1.00	1.40	.80	.....
13	3.05	1.40	1.05	.75	.90	(a)	29	1.95	1.05	.95	1.10	.90	.....
14	3.00	1.40	1.05	1.15	.95	(a)	30	1.90	1.05	.85	1.05	.70	.....
15	2.95	1.25	1.15	1.10	.95	(a)	31	1.80	1.05	.....	1.35	.....	.....
16	2.85	1.30	1.00	.85	.85	.....							

a Ice.

Daily gage height, in feet, of Bitterroot River at Missoula, Montana, for 1898.

Day.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Day.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	.....	2.45	1.40	1.50	1.75	1.60	17	4.00	1.60	1.35	1.85	1.55	.....
2	.....	2.30	1.50	1.45	1.75	1.60	18	3.80	1.60	1.30	1.80	1.60	.....
3	.....	2.25	1.70	1.45	1.75	1.50	19	3.60	1.60	1.25	1.80	1.75	.....
4	.....	2.15	1.70	1.50	1.75	1.40	20	3.40	1.60	1.20	1.75	1.70	.....
5	.....	2.10	1.75	1.45	1.80	1.40	21	3.20	1.45	1.15	1.70	1.70	.....
6	5.40	2.00	1.70	1.45	1.80	1.40	22	3.10	1.40	1.20	1.65	1.55	.....
7	5.15	1.95	1.65	1.45	1.85	1.80	23	3.00	1.45	1.35	1.85	1.65	.....
8	4.90	1.90	1.60	1.45	1.85	2.00	24	3.10	1.45	1.35	1.85	1.70	.....
9	4.75	1.85	1.55	1.45	1.85	2.80	25	2.90	1.40	1.40	1.85	1.65	.....
10	4.75	1.85	1.50	1.45	1.80	2.80	26	2.85	1.40	1.45	1.85	1.60	.....
11	4.70	1.75	1.45	1.50	1.75	.....	27	2.80	1.35	1.50	1.85	1.60	.....
12	4.65	1.75	1.45	1.60	1.70	.....	28	2.65	1.35	1.45	1.85	1.60	.....
13	4.65	1.60	1.40	1.55	1.65	.....	29	2.60	1.35	1.45	1.90	1.55	.....
14	4.50	1.60	1.35	1.55	1.65	.....	30	2.55	1.30	1.45	1.80	1.55	.....
15	4.40	1.60	1.35	1.55	1.55	.....	31	2.50	1.35	.....	1.80	.....	.....
16	4.20	1.60	1.35	1.85	1.55	.....							

Daily gage height, in feet, of Missoula River at Missoula, Montana, for 1898.

Day.	July.	Aug.	Sept.	Oct.	Nov.	Dec.	Day.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	.....	3.45	2.75	2.75	2.75	2.65	17	4.53	2.85	2.73	2.75	2.60	.....
2	.....	3.40	2.80	2.75	2.75	2.65	18	4.45	2.85	2.70	2.75	2.68	.....
3	.....	3.35	2.80	2.75	2.75	2.65	19	4.38	2.85	2.68	2.78	2.70	.....
4	.....	3.28	2.80	2.75	2.75	2.65	20	4.23	2.85	2.65	2.80	(a)	.....
5	.....	3.23	2.80	2.75	2.78	(a)	21	4.08	2.80	2.65	2.75	(a)	.....
6	.....	3.20	2.85	2.75	2.80	(a)	22	3.95	2.80	2.73	2.75	(a)	.....
7	.....	3.18	2.80	2.75	2.75	(a)	23	3.95	2.80	2.75	2.78	(a)	.....
8	.....	3.13	2.80	2.75	2.75	(a)	24	4.00	2.80	2.75	2.80	2.75	.....
9	.....	3.05	2.80	2.75	2.70	(a)	25	3.95	2.78	2.75	2.83	2.75	.....
10	5.28	3.05	2.80	2.75	2.70	(a)	26	3.90	2.75	2.70	2.80	2.75	.....
11	5.13	3.00	2.75	2.90	2.70	.....	27	3.75	2.75	2.70	2.80	2.75	.....
12	4.98	2.95	2.75	2.83	2.65	.....	28	3.68	2.75	2.70	2.80	2.75	.....
13	4.85	2.90	2.75	2.75	2.65	.....	29	3.60	2.70	2.75	2.80	2.75	.....
14	4.80	2.90	2.75	2.75	2.65	.....	30	3.53	2.70	2.75	2.80	2.75	.....
15	4.73	2.88	2.75	2.75	2.60	.....	31	3.50	2.73	.....	2.80	.....	.....
16	4.63	2.85	2.75	2.75	2.60	.....							

a Ice.

Daily gage height, in feet, of Lake Chelan, Lakeside, Washington, for 1897.

Day.	Sept.	Oct.	Day.	Sept.	Oct.	Day.	Sept.	Oct.	Day.	Sept.	Oct.
1	8.15	7.18	8	7.90	7.05	15	7.40	.....	22	7.33	.....
2	8.10	7.15	9	7.95	7.03	16	7.38	.....	23	7.33	.....
3	8.65	7.15	10	7.90	7.02	17	7.35	.....	24	7.30	.....
4	8.70	7.12	11	7.65	.....	18	7.33	.....	25	7.30	.....
5	8.00	7.10	12	7.55	.....	19	7.35	.....	26	7.28	.....
6	8.10	7.08	13	7.50	7.00	20	7.33	.....	27	7.25	.....
7	8.00	7.07	14	7.45	7.00	21	7.33	.....	30	7.20	.....

Daily gage height, in feet, of Lake Chelan at Lakeside, Washington, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	7.40	6.70	7.35	7.05	8.50	11.35	11.05	9.70	8.40	7.45	7.00	6.65
2	7.40	6.70	7.35	7.05	8.60	11.20	11.00	9.70	8.35	7.40	7.00	6.60
3	7.35	6.75	7.35	7.10	8.75	11.15	10.90	9.65	8.25	7.30	6.95	6.60
4	7.30	6.75	7.40	7.10	8.90	11.00	10.90	9.65	8.15	7.25	6.95	6.60
5	.....	6.75	7.40	7.15	9.05	10.90	10.85	9.65	8.10	7.20	6.90	6.60
6	.....	6.80	7.40	7.15	9.20	10.85	10.80	9.60	8.00	7.15	6.95	6.65
7	7.20	6.80	7.45	7.20	9.40	11.05	10.80	9.60	7.95	7.10	6.95	6.65
8	7.20	6.80	7.45	7.20	9.50	11.25	10.75	9.60	7.90	7.10	7.00	6.70
9	7.15	6.85	7.45	7.25	9.60	11.40	10.70	9.55	7.90	7.15	7.05	6.70
10	7.10	6.85	7.50	7.25	9.65	11.90	10.70	9.50	7.85	7.15	7.00	6.70
11	7.10	6.90	7.50	7.30	9.75	12.00	10.65	9.45	7.80	7.10	7.00	6.75
12	.....	6.90	7.50	7.30	9.80	12.20	10.70	9.40	7.80	7.10	6.95	6.75
13	7.05	6.90	7.45	7.35	9.90	12.30	10.80	9.40	7.85	7.15	6.95	6.75
14	7.00	6.95	7.45	7.40	10.05	12.40	10.85	9.35	7.85	7.20	6.90	6.75
15	7.00	6.95	7.40	7.40	10.25	12.50	10.75	9.30	7.80	7.20	6.90	6.80
16	6.95	7.00	7.40	7.45	10.50	12.40	10.60	9.20	7.75	7.15	6.90	6.80
17	6.90	7.05	7.35	7.55	10.90	12.45	10.50	9.10	7.70	7.15	6.85	6.80
18	.....	7.05	7.35	7.65	11.15	12.30	10.35	9.05	7.70	7.10	6.85	6.80
19	6.85	7.10	7.30	7.75	11.30	12.35	10.25	9.00	7.75	7.10	6.80	6.80
20	6.80	7.10	7.30	7.80	11.30	12.45	10.15	8.95	7.75	7.15	6.80	6.85
21	.....	7.15	7.25	7.85	11.35	12.20	10.05	8.90	7.70	7.15	6.80	6.85
22	.....	7.20	7.25	7.90	11.25	12.20	9.95	8.85	7.70	7.20	6.75	6.85
23	.....	7.20	7.25	7.95	11.20	12.15	9.90	8.80	7.70	7.25	6.75	6.90
24	6.70	7.25	7.20	8.00	11.05	12.05	9.85	8.80	7.65	7.25	6.70	6.90
25	6.65	7.25	7.20	8.10	11.00	10.00	9.85	8.75	7.65	7.20	6.70	6.90
26	6.65	7.25	7.15	8.15	10.95	11.95	9.80	8.70	7.65	7.20	6.75	6.95
27	6.60	7.30	7.15	8.20	11.25	11.90	9.80	8.65	7.60	7.15	6.75	6.95
28	6.60	7.30	7.10	8.25	11.30	11.80	9.75	8.60	7.60	7.10	6.70	7.00
29	6.65	.....	7.10	8.35	11.35	11.50	9.75	8.55	7.55	7.10	6.65	7.05
30	6.65	.....	7.10	8.40	11.45	11.15	9.75	8.55	7.50	7.05	6.65	7.05
31	6.70	.....	7.05	.....	11.45	.....	9.70	8.50	.....	7.05	.....	7.05

Daily gage height, in feet, of Naches River at North Yakima, Washington, for 1898.

Day.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	4.0	5.30	4.70	.....	6.40	5.70	4.70	4.00	3.90	4.00	4.00
2	.....	5.30	4.70	7.10	6.30	5.80	4.70	4.00	.....	4.00	4.00
3	.....	5.30	.....	7.10	6.20	.....	4.70	4.00	3.90	4.10	4.00
4	.....	5.40	4.70	7.10	6.20	5.90	4.60	.....	3.90	4.20	.....
5	.....	5.40	4.80	6.90	.....	5.90	4.60	3.90	3.90	4.30	3.90
6	.....	.....	5.00	6.90	6.70	5.80	4.50	3.90	3.90	.....	3.80
7	4.8	5.50	5.20	6.90	7.00	5.60	.....	3.90	3.90	4.30	3.80
8	.....	5.50	5.20	.....	7.00	5.50	4.40	3.90	3.90	4.20	3.70
9	.....	5.50	5.20	6.90	7.00	5.50	4.40	3.90	.....	4.20	3.70
10	.....	5.40	.....	6.90	7.60	.....	4.40	3.90	3.90	4.20	3.70
11	.....	5.40	5.40	7.40	7.70	5.50	4.40	.....	3.90	4.10	.....
12	.....	5.30	5.60	7.40	.....	5.60	4.40	3.90	4.00	4.10	3.70
13	.....	.....	5.80	7.40	7.20	5.60	4.30	3.90	4.00	.....	3.70
14	.....	5.30	6.20	7.40	7.10	5.50	.....	3.90	4.10	4.00	3.80
15	8.30	5.20	6.50	.....	7.10	5.30	4.30	3.90	4.20	4.00	3.90
16	.....	5.10	6.60	7.40	7.40	5.10	4.20	3.90	.....	4.00	3.90
17	.....	5.10	.....	8.10	7.40	.....	4.10	3.90	4.50	4.00	3.90
18	.....	5.00	6.40	8.10	6.90	5.10	4.10	.....	4.50	4.30	.....
19	.....	5.00	6.30	7.90	.....	5.10	4.10	3.90	4.30	4.40	3.90
20	.....	.....	6.20	7.30	7.00	5.10	4.10	3.90	4.30	.....	3.90
21	.....	4.90	6.20	6.90	6.70	4.90	.....	3.90	4.20	4.40	3.90
22	5.90	4.80	6.20	.....	6.40	4.90	4.10	4.10	4.20	4.30	3.80
23	.....	4.70	6.20	6.50	6.20	4.80	4.00	4.30	.....	4.30	3.80
24	.....	4.60	.....	6.50	6.20	.....	4.00	4.30	4.10	4.20	3.70
25	.....	4.60	6.70	6.60	6.20	4.80	4.00	.....	4.10	4.20	.....
26	.....	4.60	7.20	6.70	.....	4.80	4.00	4.20	4.10	4.20	3.90
27	.....	.....	7.30	6.90	6.10	4.80	4.00	4.10	4.10	.....	4.50
28	.....	4.60	7.30	7.10	5.90	4.80	.....	4.10	4.10	4.20	5.90
29	.....	4.60	7.20	.....	5.80	4.70	4.00	3.90	4.10	4.20	5.90
30	.....	4.60	7.20	6.80	5.70	4.70	4.00	3.90	.....	4.10	5.60
31	.....	4.70	.....	6.50	.....	.....	4.00	.....	4.00	.....	5.10

Daily gage height, in feet, of Yakima River at Union Gap, Washington, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	8.00	5.20	7.00	6.00	8.80	7.80	6.90	5.50	4.40	4.60	4.80	5.20
2	7.70	5.20	7.00	6.00	8.80	8.00	6.80	5.40	4.40	4.60	4.80	5.20
3	7.40	5.20	7.00	6.00	8.80	7.80	6.80	5.30	4.40	4.60	4.90	5.10
4	7.20	5.20	7.10	6.10	9.20	7.60	7.00	5.30	4.40	4.70	5.10	5.10
5	7.00	5.20	7.50	6.10	9.20	7.60	6.70	5.30	4.40	4.60	5.30	5.10
6	6.80	5.80	7.60	6.30	9.20	8.00	6.80	5.20	4.40	4.60	5.30	4.90
7	6.60	6.00	7.60	6.60	9.00	8.60	6.70	5.10	4.30	4.60	5.30	4.80
8	6.50	6.20	7.30	6.60	9.00	9.00	6.60	5.10	4.30	4.60	5.70	4.70
9	6.40	6.10	7.20	6.60	8.00	9.30	6.50	5 10	4.30	4.60	5.70	4.70
10	6.20	6.10	7.10	6.70	8.50	9.50	6.40	5.10	4.30	4.60	5.60	4.60
11	6.10	6.00	7.10	7.10	9.10	9.70	6.50	5.00	4.30	4.60	5.50	4.60
12	6.10	6.00	7.00	7.20	9.20	9.20	6.50	5.00	4.30	4.60	5.40	4.60
13	6 00	5.90	6.90	7.30	9.40	9.10	6.50	4.90	4.30	4.70	5.20	4.70
14	5.90	9.00	6.80	7.80	9.40	9.10	6.50	4.80	4.30	4.20	5.20	4.70
15	5.90	11.10	6.80	7.20	9.70	9.00	6.50	4.80	4.20	4.20	5.20	4.70
16	5.90	10 80	6.70	7.20	10.00	9.10	6.50	4.80	4.20	5.20	5.10	4.80
17	5 80	10.10	6.60	8.20	10.20	8.70	6.20	4.70	4.20	5.20	5.10	4.80
18	5.70	9.30	6.50	8.20	10.40	8.50	6.10	4.70	4.30	5.20	5.60	4.70
19	5.70	8.60	6.40	8.00	10.20	8.50	6.00	4.70	4.30	5.20	5.80	4.70
20	5.60	8.40	6.40	7.90	9.60	8.60	6.00	4.60	4.30	5.20	5.80	4.70
21	5.60	8.10	6.40	7.80	9.10	8.50	5.90	4.60	4.40	5.10	5.70	4.60
22	5.60	7.80	6.30	7.80	9.00	8.30	5.80	4.60	4.40	5.00	5.60	4.60
23	5.50	7 60	6.30	7.80	8.50	7.80	5.70	4.60	4.50	5.00	5.50	4.60
24	5.50	7.40	6.20	8.20	8.20	7.60	5.60	4.50	4.50	5.00	5.40	4.60
25	5.50	7.20	6.20	8.20	8.10	7.60	5.60	4.50	4.50	4.90	5.30	4.60
26	5.40	7.10	6.10	8.80	8.10	7.80	5.50	4.50	4.50	4.90	5.30	4.50
27	5.40	7.00	6.10	9.10	8.10	7.40	5.50	4.50	4.50	4.80	5.20	4.50
28	5.40	7.00	6.00	9.00	8.70	7.30	5.50	4.50	4.50	4.80	5.20	6.80
29	5.30	.....	6.00	8.90	9.00	7.20	5.50	4.40	4.50	4.80	5.30	8.50
30	5.30	.....	5.90	9.00	8.60	7.00	5.50	4.40	4.50	4.80	5.20	7.80
31	5.30	.....	5.90	.....	8.30	.....	5.50	4.40	.....	4.80	.....	7.30

Daily gage height, in feet, of Yakima River at Kiona, Washington, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	10.15	5.60	7.72	6.10	10.18	9.10	7.25	5.19	.....	4.18	4.56	5.05
2	9.55	5.50	7.72	6.19	10.10	8.95	7.10	5.20	4.02	4.21	4.51	5.00
3	9.00	5.46	7.73	.....	10.00	8.73	.....	5.14	4.00	4.25	4.56	5.00
4	8.55	5.35	.....	6.15	10.08	8.50	.....	5.10	3.95	4.27	4.68	4.95
5	8.20	5.32	7.85	6.15	10.45	8.38	.....	5.17	3.90	4.30	4.96	4.90
6	7.90	5.60	7.98	.....	10.55	8.61	.....	5.03	3.95	4.31	4.95	4.85
7	7.60	6.05	8.02	6.50	.....	9.23	.....	5.04	3.92	4.33	5.32	4.80
8	7.35	6.72	8.15	6.82	10.23	9.79	7.05	4.90	3.90	4.29	5.40	4.53
9	7.10	6.80	8.18	6.82	9.85	10.19	6.71	4.88	3.87	4.25	5.56	4.20
10	6.90	6.60	7.98	6.76	9.66	10.50	6.67	4.82	3.84	4.20	5.50	4.40
11	6.60	6.60	7.91	6.85	10.08	10.72	.....	4.80	.....	4.22	5.41	4.40
12	6.50	6.70	7.75	6.90	10.51	10.90	6.68	4.75	.....	4.24	5.34	4.35
13	6.50	6.72	7.82	7.00	10.75	10.56	6.66	.....	3.79	4.30	5.24	4.05
14	6.45	6.75	7.75	7.61	10.78	10.13	6.55	.....	3.76	4.35	5.12	4.10
15	6.30	11.25	.....	8.32	10.83	10.02	6.54	.....	3.78	4.35	5.04	4.15
16	6.20	12.45	7.42	8.95	.....	10.17	6.40	4.43	3.78	4.60	4.94	4.40
17	6.12	13.27	7.30	9.20	.....	10.14	6.29	4.34	3.77	4.93	4.95	4.45
18	6.04	13.21	7.15	9.21	12.00	9.76	6.17	4.29	3.74	4.95	4.90	4.64
19	6.00	12.07	6.93	9.05	12.10	9.45	6.05	4.27	3.71	5.00	5.22	4.75
20	5.95	10.92	6.93	8.95	11.85	9.65	6.03	4.26	3.69	5.02	5.50	4.60
21	5.90	10.10	6.82	8.75	10.80	9.50	5.98	.....	3.76	4.93	5.56	4.56
22	5.85	9.62	6.73	8 65	10 20	9.15	5.78	4.20	3.78	4.86	5.60	4.50
23	5.80	9.20	6.64	8.62	9.82	8.60	5.69	4.17	3.80	4.88	5.50	4.45
24	5.75	8.72	6.50	8 82	9.60	8.37	5.67	4.16	3.84	4.72	5.40	4.40
25	5.70	8.46	6.53	9.00	9.38	8.26	5.52	4.17	3.80	4.68	5.25	4.44
26	5.10	8.33	6.47	9.45	9.06	8.20	5.50	4.13	3.84	4.63	5.20	4.45
27	5.20	7.98	6.38	10.20	9.50	7.94	5.46	4.10	3.87	4.60	5.15	4.75
28	5.15	7.76	6.28	10.29	10.02	7.82	5.44	4.10	3.90	4.57	5.10	4.90
29	5.10	.....	6.18	10.23	10.08	7.62	5.42	4.08	4.00	4.53	5.15	7.50
30	5.35	.....	6.14	10.18	9.80	7.42	5.33	4.04	4.10	4.56	5.10	8.50
31	5.52	.....	6.10	.....	9.51	.....	5.24	4.01	.....	4.54	.....	8.15

Daily gage height, in feet, of Spokane River at Spokane, Washington, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	5.60	3.00	6.70	4.35	10.40	9.90	5.85	2.95	2.00	1.75	1.95	2.20
2	5.70	3.00	6.60	4.30	10.40	9.85	5.70	2.90	2.00	1.75	2.00	2.20
3	5.70	2.90	6.50	4.25	10.35	9.80	5.50	2.85	2.00	1.75	2.00	2.20
4	5.65	2.90	6.40	4.20	10.25	9.65	5.40	2.80	1.90	1.75	2.05	2.15
5	5.60	2.95	6.45	4.25	10.10	9.40	5.25	2.75	1.90	1.75	2.10	2.15
6	5.45	2.95	6.55	4.30	10.10	9.25	5.10	2.70	1.85	1.75	2.10	2.15
7	5.35	3.00	6.60	4.45	9.95	9.10	4.95	2.70	1.80	1.75	2.15	2.10
8	5.25	3.20	6.65	4.60	9.90	9.00	4.80	2.65	1.80	1.75	2.15	2.10
9	5.10	3.50	6.70	4.75	9.75	8.85	4.70	2.60	1.80	1.80	2.20	2.10
10	5.00	3.90	6.70	4.90	9.60	8.80	4.55	2.55	1.80	1.75	2.20	2.05
11	4.90	4.10	6.70	5.10	9.40	8.75	4.45	2.50	1.80	1.75	2.25	2.00
12	4.70	4.30	6.65	5.30	9.40	8.65	4.40	2.50	1.80	1.75	2.25	2.00
13	4.60	4.50	6.60	5.50	9.45	8.60	4.30	2.45	1.80	1.75	2.25	2.00
14	4.50	4.65	6.50	5.70	9.55	8.50	4.20	2.40	1.80	1.75	2.25	1.95
15	4.40	5.40	6.40	6.10	9.60	8.45	4.15	2.35	1.80	1.75	2.25	1.95
16	4.30	6.40	6.30	6.50	9.70	8.40	4.00	2.35	1.80	1.80	2.25	1.95
17	4.20	7.10	6.10	7.10	9.80	8.20	3.90	2.30	1.80	1.85	2.20	1.90
18	4.10	7.80	6.00	7.50	9.95	8.00	3.85	2.30	1.80	1.85	2.20	1.90
19	4.00	8.20	5.90	7.70	10.10	7.90	3.80	2.25	1.80	1.85	2.20	1.90
20	4.00	8.20	5.80	7.90	10.20	7.80	3.70	2.20	1.80	1.85	2.20	1.90
21	3.90	8.10	5.50	8.10	10.10	7.60	3.65	2.20	1.80	1.90	2.20	1.90
22	3.80	8.10	5.50	8.20	10.00	7.40	3.55	2.20	1.75	1.90	2.25	1.99
23	3.70	7.80	5.40	8.40	9.80	7.25	3.50	2.20	1.75	1.90	2.25	1.90
24	3.60	7.60	5.20	8.60	9.55	7.05	3.40	2.20	1.75	1.90	2.25	1.90
25	3.50	7.50	5.10	8.75	9.40	6.95	3.30	2.15	1.75	1.90	2.25	1.90
26	3.40	7.30	5.00	8.80	9.20	6.80	3.30	2.10	1.75	1.90	2.25	1.90
27	3.35	7.10	4.90	9.15	9.15	6.60	3.20	2.10	1.75	1.90	2.25	1.90
28	3.30	6.80	4.80	9.60	9.15	6.40	3.15	2.05	1.75	1.90	2.25	1.90
29	3.20	.....	4.65	10.15	9.30	6.15	3.10	2.00	1.75	1.95	2.20	2.00
30	3.15	.....	4.50	10.30	9.60	5.95	3.05	2.00	1.75	1.95	2.20	2.20
31	3.05	.....	4.40	.....	9.80	.....	3.00	2.00	.....	1.95	.....	2.35

Daily gage height, in feet, of Wallawalla River at Whitman, Washington, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	2.85	2.00	2.88	2.50	3.28	2.25	1.20	1.05	1.10	1.30	1.50	1.80
2	2.68	2.00	2.80	2.80	3.23	2.20	1.20	1.05	1.10	1.30	1.50	1.90
3	2.70	2.00	2.75	2.80	3.18	2.20	1.20	1.05	1.10	1.35	1.50	1.90
4	2.63	2.05	2.75	2.80	3.05	2.15	1.20	1.03	1.15	1.35	1.50	1.88
5	2.50	2.10	2.68	3.20	2.98	2.10	1.20	1.00	1.15	1.35	1.50	1.80
6	2.75	2.60	2.60	3.85	2.88	2.05	1.20	1.00	1.20	1.35	1.50	1.65
7	2.90	3.10	2.68	3.63	2.75	2.00	1.15	1.00	1.20	1.40	1.50	1.63
8	2.93	3.80	2.78	3.38	2.70	1.95	1.15	1.00	1.20	1.40	1.50	1.60
9	2.90	3.32	2.68	3.25	2.65	1.88	1.15	1.00	1.20	1.40	1.50	1.60
10	2.73	2.95	2.58	3.60	2.60	1.73	1.15	1.00	1.15	1.40	1.50	1.55
11	2.63	2.80	2.48	3.53	2.63	1.65	1.15	1.00	1.15	1.40	1.50	1.55
12	2.55	2.88	2.45	3.73	2.68	1.65	1.15	1.00	1.15	1.45	1.50	1.50
13	2.50	3.08	2.45	3.80	2.58	1.65	1.15	1.00	1.10	1.45	1.50	1.50
14	2.45	4.23	2.40	3.80	2.50	1.65	1.15	1.00	1.10	1.45	1.50	1.50
15	2.43	4.85	2.35	3.75	2.45	1.65	1.15	1.00	1.10	1.45	1.50	1.50
16	2.40	4.75	2.30	3.63	2.43	1.65	1.15	1.00	1.13	1.45	1.50	1.50
17	2.35	4.00	2.23	3.55	2.40	1.65	1.15	1.00	1.13	1.45	1.55	1.50
18	2.30	4.18	2.20	3.33	2.35	1.68	1.10	1.00	1.13	1.45	1.55	1.50
19	2.30	3.18	2.20	3.20	2.35	1.60	1.10	1.00	1.15	1.45	1.63	1.58
20	2.35	3.00	2.18	3.35	2.30	1.55	1.10	1.00	1.15	1.45	1.75	1.75
21	2.35	3.05	2.10	3.53	2.25	1.50	1.10	1.00	1.15	1.45	1.83	1.75
22	2.38	2.90	2.05	3.65	2.43	1.45	1.10	1.00	1.20	1.45	1.90	1.75
23	2.18	2.70	2.05	3.60	2.33	1.40	1.10	1.00	1.20	1.45	1.90	1.95
24	2.00	2.68	2.10	3.55	2.25	1.35	1.10	1.05	1.20	1.45	1.90	2.13
25	2.00	2.63	2.05	3.55	2.25	1.30	1.10	1.05	1.25	1.45	1.90	2.25
26	2.00	2.55	2.05	4.40	2.28	1.25	1.10	1.10	1.25	1.45	1.80	2.40
27	2.00	2.50	2.05	4.10	2.45	1.20	1.10	1.10	1.25	1.50	1.80	2.78
28	2.00	2.73	2.05	3.83	2.58	1.20	1.10	1.10	1.25	1.50	1.80	3.40
29	2.08	.....	2.05	3.63	2.53	1.20	1.08	1.10	1.25	1.50	1.80	3.73
30	2.00	.....	2.05	3.30	2.43	1.25	1.05	1.10	1.25	1.50	1.80	3.55
31	2.00	.....	2.25	.....	2.33	.....	1.05	1.10	.....	1.50	.....	3.20

Daily gage height, in feet, of Umatilla River at Gibbon, Oregon, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	2.70	1.10	2.25	1.80	2.85	1.85	0.55	0.30	0.20	0.30	0.45	1.40
2	2.50	1.30	2.35	2.30	2.75	1.70	.55	.25	.20	.30	.45	1.30
3	2.20	1.30	2.35	2.50	2.65	1.60	.55	.25	.20	.30	.45	1.20
4	2.00	1.70	2.50	2.60	2.45	1.50	.55	.25	.20	.30	.55	1.00
5	1.90	2.10	2.55	3.10	2.45	1.45	.50	.25	.20	.30	.50	.90
6	2.10	2.40	2.55	3.15	2.30	1.40	.50	.25	.20	.30	.50	.85
7	2.00	2.30	3.00	3.30	2.25	1.30	.50	.25	.20	.30	.45	.80
8	2.00	2.15	3.10	3.30	2.15	1.30	.50	.25	.20	.30	.45	.70
9	2.00	2.10	3.00	3.20	2.10	1.20	.45	.25	.20	.30	.50	.65
10	1.90	2.10	2.60	3.50	2.10	1.15	.45	.25	.20	.30	.50	.60
11	1.85	2.10	2.40	3.20	2.05	1.10	.45	.25	.20	.35	.50	.60
12	1.80	2.40	2.30	3.30	2.00	1.05	.45	.20	.20	.35	.50	.55
13	1.60	2.65	2.15	3.60	1.95	1.05	.45	.20	.20	.35	.50	.50
14	1.60	5.60	2.05	4.30	1.95	1.00	.45	.20	.20	.35	.55	.50
15	1.50	5.15	1.85	4.30	1.90	1.00	.45	.20	.20	.35	.55	.45
16	1.50	4.70	1.85	4.00	1.95	.95	.45	.20	.20	.35	.55	.50
17	1.45	3.65	1.80	3.65	1.90	.90	.45	.20	.20	.35	.60	.55
18	1.40	2.80	1.75	3.40	1.80	.85	.40	.20	.20	.35	.65	.60
19	1.40	2.55	1.75	3.20	1.65	.85	.40	.20	.20	.35	.80	.70
20	1.40	2.25	1.70	3.20	1.50	.80	.40	.20	.20	.35	.80	.80
21	1.35	2.25	1.65	3.25	1.40	.75	.40	.20	.20	.35	.80	.80
22	1.35	2.15	1.65	3.20	1.60	.70	.40	.20	.20	.35	.80	.80
23	1.35	2.10	1.65	3.40	1.55	.70	.40	.20	.30	.35	.85	.80
24	1.30	2.00	1.60	3.45	1.40	.70	.35	.20	.30	.35	.85	.75
25	1.25	1.90	1.60	4.00	1.30	.65	.35	.20	.25	.35	.80	.85
26	1.25	1.90	1.55	3.80	1.40	.65	.35	.20	.25	.40	.75	.90
27	1.20	1.90	1.55	3.40	1.65	.60	.35	.20	.25	.40	.75	1.60
28	1.15	2.00	1.55	3.10	1.80	.60	.35	.20	.30	.40	.75	3.00
29	1.15	.....	1.55	3.00	2.00	.60	.30	.20	.30	.40	.80	2.40
30	1.10	.....	1.50	2.90	1.90	.55	.30	.20	.30	.45	.90	1.90
31	1.10	.....	1.60	.....	1.90	.....	.30	.20	.....	.45	.....	1.75

Daily gage height, in feet, of Deschutes River at Moro, Oregon, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	2.90	2.20	2.70	2.00	2.70	2.30	2.00	1.70	1.60	1.60	1.50	1.70
2	2.70	2.20	2.80	2.10	2.70	2.30	2.00	1.70	1.60	1.60	1.50	1.70
3	2.60	2.20	2.80	2.10	2.70	2.20	1.90	1.70	1.60	1.60	1.60	1.60
4	2.60	2.20	2.80	2.10	2.60	2.20	1.90	1.70	1.70	1.60	1.60	1.70
5	2.50	2.30	2.90	2.20	2.60	2.20	2.30	1.60	1.70	1.60	1.70	1.70
6	2.50	2.30	2.90	2.20	2.60	2.10	2.30	1.60	1.70	1.60	1.60	1.60
7	2.40	2.50	2.90	2.30	2.50	2.10	2.00	1.60	1.60	1.60	1.60	1.60
8	2.40	2.70	2.80	2.40	2.50	2.20	2.00	1.60	1.60	1.60	1.60	1.50
9	2.30	2.60	2.80	2.40	2.50	2.20	1.90	1.80	1.60	1.60	1.70	1.50
10	2.30	2.80	2.80	2.40	2.40	2.30	1.90	1.80	1.60	1.60	1.70	1.40
11	2.30	2.70	2.80	2.50	2.40	2.30	1.90	1.70	1.60	1.60	1.70	1.40
12	2.30	2.60	2.70	2.50	2.50	2.30	1.80	1.70	1.60	1.60	1.80	1.40
13	2.30	2.70	2.60	2.60	2.50	2.40	1.80	1.70	1.50	1.50	1.80	1.30
14	2.40	3.10	2.50	2.80	2.50	2.40	1.80	1.60	1.50	1.50	1.90	1.20
15	2.30	3.60	2.40	3.00	2.60	2.50	1.80	1.60	1.50	1.50	1.90	1.20
16	2.30	3.80	2.40	3.10	2.60	2.50	1.70	1.60	1.60	1.50	2.00	1.10
17	2.30	3.70	2.30	3.10	2.50	2.60	1.70	1.60	1.60	1.50	2.10	1.10
18	2.30	3.60	2.30	3.00	2.50	2.60	1.70	1.60	1.60	1.50	2.20	1.10
19	2.40	3.30	2.20	3.00	2.40	2.50	1.70	1.70	1.60	1.50	2.50	1.20
20	2.30	3.10	2.20	2.90	2.40	2.40	1.70	1.70	1.60	1.50	2.20	1.90
21	2.30	3.00	2.20	2.90	2.50	2.30	1.80	1.80	1.60	1.50	2.20	1.80
22	2.30	2.80	2.10	2.80	2.50	2.30	1.80	1.80	1.60	1.50	2.10	1.80
23	2.20	2.80	2.10	2.90	2.40	2.30	2.00	1.70	1.70	1.40	1.90	1.70
24	2.20	2.70	2.10	2.90	2.40	2.20	2.00	1.70	1.70	1.40	1.90	1.70
25	2.20	2.70	2.20	2.90	2.40	2.20	1.90	1.70	1.70	1.40	1.80	1.60
26	2.10	2.60	2.20	2.90	2.30	2.10	1.90	1.70	1.70	1.40	1.80	1.60
27	2.10	2.60	2.10	3.00	2.40	2.10	1.80	1.60	1.70	1.40	1.90	1.70
28	2.10	2.60	2.10	2.90	2.50	2.10	1.70	1.60	1.60	1.40	1.90	1.80
29	2.10	.....	2.00	2.80	2.50	2.00	1.70	1.60	1.60	1.50	1.80	1.90
30	2.10	.....	2.00	2.80	2.40	2.00	1.80	1.60	1.60	1.50	1.80	1.80
31	2.20	.....	2.00	.....	2.40	.....	1.80	1.60	.....	1.50	.....	1.80

Daily gage height, in feet, of Hood River at Tucker, Oregon, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	4.60	2.60	3.50	2.40	3.50	3.20	2.50	2.40	1.70	2.40	1.60	4.40
2	4.60	2.50	3.50	2.40	3.50	3.10	2.50	2.40	1.60	2.20	1.60	4.20
3	4.00	2.50	3.50	2.40	3.50	2.90	2.60	2.30	1.60	2.20	2.00	4.00
4	3.90	2.70	3.50	2.40	3.40	2.80	2.60	2.20	1.60	2.10	4.00	3.80
5	3.80	3.60	3.40	2.40	3.40	2.90	2.60	2.20	1.60	1.90	3.60	3.60
6	4.00	4.60	3.40	2.40	3.30	3.30	2.50	2.20	1.60	1.90	3.00	3.20
7	3.60	5.60	3.50	2.70	3.30	3.40	2.50	2.20	1.60	1.80	2.80	3.00
8	3.50	4.80	3.50	2.70	3.30	3.40	2.50	2.20	1.60	1.70	2.60	2.80
9	3.40	4.60	3.40	2.60	3.40	3.50	2.50	2.30	1.60	1.80	2.50	2.40
10	3.20	4.00	3.30	2.60	3.40	3.40	2.60	2.30	1.80	2.00	2.30	2.20
11	3.00	3.80	3.20	2.50	3.40	3.40	2.60	2.40	1.80	2.00	2.00	2.20
12	3.00	5.20	3.20	2.60	3.50	3.40	2.60	2.30	1.70	2.00	2.00	2.10
13	3.00	6.00	3.10	3.00	3.50	3.40	2.70	2.20	1.70	2.00	1.90	2.00
14	3.10	8.70	3.00	3.40	3.60	3.40	2.50	2.20	1.70	2.00	1.90	2.00
15	3.50	8.60	3.00	3.50	3.50	3.40	2.40	2.20	1.70	3.30	1.90	2.00
16	3.80	7.60	3.00	3.50	3.40	3.30	2.40	2.10	1.70	2.80	1.90	2.10
17	3.20	6.00	2.80	3.40	3.40	3.20	2.70	2.00	1.70	2.60	4.00	2.10
18	3.20	5.30	2.70	3.20	3.40	3.20	2.50	2.00	1.80	2.50	6.00	2.30
19	4.00	4.50	2.60	3.10	3.40	3.20	2.30	1.90	1.80	2.30	4.80	3.10
20	3.70	4.30	2.60	3.20	3.40	3.10	2.20	1.80	1.80	2.10	4.30	2.70
21	3.30	4.50	2.80	3.20	3.50	3.10	2.20	1.80	2.60	2.00	3.00	2.60
22	3.20	4.10	2.60	3.50	3.60	3.00	2.20	1.90	2.30	1.90	2.90	2.50
23	3.20	4.00	2.60	4.00	3.40	2.90	2.40	1.90	2.60	1.90	2.80	2.30
24	3.00	3.90	2.70	4.00	3.30	2.80	2.30	2.00	1.80	1.80	2.70	2.20
25	3.00	3.50	2.60	4.10	3.30	2.80	2.30	2.00	1.60	1.70	2.60	2.30
26	3.00	3.50	2.50	4.70	3.30	2.80	2.20	2.00	1.60	1.70	2.60	3.30
27	2.90	3.50	2.50	4.30	3.30	2.80	2.20	2.00	1.60	1.70	2.60	3.60
28	2.80	3.50	2.50	4.00	3.20	2.70	2.30	2.00	1.60	1.70	2.10	5.00
29	2.60	.....	2.50	3.90	3.20	2.60	2.30	1.90	2.20	1.70	3.00	4.80
30	2.70	.....	2.50	3.80	3.10	2.50	2.40	1.80	3.20	1.60	3.50	4.50
31	2.70	.....	2.40	.....	3.00	.....	2.50	1.70	.....	1.60	.....	4.30

List of discharge measurements, 1898.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
				Feet.	*Sec.-ft.*
Mar. 16	Portneuf River	Pocatello, Idaho	F. J. Mills	7.85	286
Apr. 28	do	do	do	8.90	562
June 14	do	do	do	7.75	293
July 31	do	do	C. C. Babb	6.40	47
Do.	do	do	do	6.70	87
Oct. 9	do	do	F. S. Shirley	6.90	143
Aug. 26	Snake River	Montgomery, Idaho	C. C. Babb	1.90	2,831
Oct. 11	do	do	F. S. Shirley	2.50	5,110
Mar. 17	Malad River	Toponis, Idaho	F. J. Mills	2.80	72
May 22	do	do	do	3.60	324
Mar. 17	Little Wood River	do	do	4.20	137
Oct. 10	do	do	F. S. Shirley	3.10	63
Apr. 16	Boise River	Boise, Idaho	F. J. Mills	4.20	5,248
June 15	do	do	F. S. Shirley	4.20	6,710
Aug. 3	do	do	C. C. Babb	1.25	872
Aug. 24	do	do	do	1.00	698
Oct. 18	do	do	F. S. Shirley	1.20	845
Apr. 12	Weiser River	Weiser, Idaho	F. J. Mills	3.20	1,914
June 2	do	do	do	3.80	2,305
Aug. 6	do	do	C. C. Babb	.40	42
Oct. 14	do	do	F. S. Shirley	.80	172
Mar. 10	Palouse River	Hooper, Wash	Sydney Arnold	7.50	2,779
June 21	do	do	do	3.00	223
July 7	Blackfoot River	Bonner, Mont	C. C. Babb	4.00	5,518
July 13	do	do	M. J. Elrod	3.10	3,357
July 25	do	do	do	2.20	2,038
Aug. 12	do	do	do	1.50	1,236
Sept. 3	do	do	do	1.10	1,055
Oct. 1	do	do	do	1.00	917
Nov. 5	do	do	Fred. D. Smith	.90	913
July 6	Bitterroot River	Missoula, Mont	C. C. Babb	5.40	7,957
July 13	do	do	M. J. Elrod	4.60	5,456
July 25	do	do	do	2.90	2,579
Aug. 12	do	do	do	1.75	1,100
Sept. 3	do	do	do	1.70	1,280
Oct. 1	do	do	do	1.50	1,061
Nov. 5	do	do	Fred. D. Smith	1.90	1,483

List of discharge measurements, 1898—Continued.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
				Feet.	*Sec.-ft.*
Oct. 29	Bitterroot River..	Harlan Bridge, near Como, Mont.	C. C. Babb		333
Dec. 26	....do	Hamilton, Mont	H. S. Lord		430
July 5	Missoula River	Missoula, Mont	C. C. Babb	6.15	10,674
July 16	....do	....do	M. J. Elrod	4.65	5,381
July 30	....do	....do	....do	3.50	3,064
Aug. 19	....do	....do	....do	2.85	1,849
Sept. 15	....do	....do	....do	2.82	1,871
Oct. 22	....do	....do	....do	2.75	1,912
Sept. 8	Yakima River	Union Gap, Wash.	C. C. Babb	4.30	786
Sept. 29	....do	....do	Sydney Arnold	4.50	985
Jan. 31	....do	Kiona, Wash	....do	5.52	2,409
Apr. 26	....do	....do	....do	9.45	10,585
May 25	....do	....do	....do	9.27	9,548
July 8	....do	....do	....do	7.04	5,207
July 21	....do	....do	....do	6.05	3,908
Aug. 4	....do	....do	....do	5.20	1,815
Aug. 19	....do	....do	....do	4.27	1,011
Sept. 6	Spokane River	Spokane, Wash	....do	1.80	2,715
Oct. 8	....do	....do	C. C. Babb	1.75	2,202
May 7	Umatilla River	Gibbon, Oreg	Sydney Arnold	2.30	981
Oct. 8	....do	....do	....do	.30	83
May 6	Deschutes River	Moro, Oreg	....do	2.60	7,582
May 5	Hood River	Tucker, Oreg	....do	3.45	1,502

Rating tables.

Pocatello.		Montgomery.		Toponis. *a*		Toponis. *b*		Grandview.		Boise.	
Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage h'g't.	Discharge.
Feet.	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*
6.4	47	2.0	4,400	2.0	0	1.0	0	1.0	10	1.0	550
6.6	80	2.2	4,525	2.1	5	1.2	1	1.1	25	1.1	721
6.8	113	2.4	4,700	2.2	10	1.4	3	1.2	45	1.2	892
7.0	147	2.6	4,900	2.3	15	1.6	5	1.3	55	1.3	1,063
7.2	183	2.8	5,100	2.4	20	1.8	9	1.4	65	1.4	1,234
7.4	219	3.0	5,400	2.5	30	2.0	14	1.5	80	1.5	1,405
7.6	257	3.2	5,800	2.6	45	2.2	19	1.6	100	1.6	1,576
7.8	296	3.4	6,200	2.7	60	2.4	27	1.7	120	1.7	1,747
8.0	336	3.6	6,600	2.8	80	2.6	37	1.8	140	1.8	1,918
8.2	384	3.8	7,000	2.9	100	2.8	47	1.9	170	1.9	2,089
8.4	433	4.0	7,400	3.0	130	3.0	57	2.0	200	2.0	2,260
8.6	484	4.5	8,900	3.2	210	3.2	70	2.1	230	2.2	2,602
8.8	536	5.0	11,000	3.4	320	3.4	87	2.2	270	2.4	2,944
9.0	590	5.5	13,400	3.6	460	3.6	105	2.3	310	2.6	3,286
9.2	650	6.0	15,800	3.8	600	3.8	126	2.4	360	2.8	3,628
9.4	711	6.5	18,200	4.0	740	4.0	150	2.5	410	3.0	3,970
9.6	777	7.0	20,600	4.2	910	4.2	173	2.6	470	3.2	4,312
9.8	848	7.5	23,000	4.4	1,090	4.4	196	2.7	540	3.4	4,654
10.0	920	8.0	25,400	4.6	1,290	4.6	219	2.8	620	3.6	4,996
10.2	988	8.5	27,800	4.8	1,490	4.8	243	2.9	700	3.8	5,338
10.4	1,057	9.0	30,200	5.0	1,700	5.0	266	3.0	780	4.0	5,680
10.6	1,126	9.5	32,600	5.2	1,920	5.2	289	3.1	850	4.2	6,022
10.8	1,194	10.0	35,000	5.4	2,140	5.4	312	3.2	920	4.4	6,364
11.0	1,263	10.5	37,400	5.6	2,360	5.6	335	3.3	1,000	4.6	6,706
11.2	1,331	11.0	39,800	5.8	2,580	5.8	358	3.4	1,080	4.8	7,048
11.4	1,400	11.5	42,200	6.0	2,800	6.0	382	3.5	1,160	5.0	7,390
11.6	1,469	12.0	44,600	6.2	3,020	6.2	405	4.0	1,610	5.2	7,732
11.8	1,537	12.5	47,000	6.4	3,240	6.4	418	5.0	2,300	5.4	8,074
12.0	1,606	13.0	49,400	6.6	3,460	6.6	451	6.0	3,060	5.6	8,416
13.0	1,950	.....	.....	6.8	3,680	6.8	474	7.0	3,850	5.8	8,758

a Rating table for Malad River.

b Rating table for Little Wood River.

Rating tables—Continued.

Weiser.		Hooper.		Bonner.		Missoula.*a*		Missoula.*b*	
Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*
0.6	80	1.5	10	0.7	850	1.3	950	2.6	1,620
.8	120	1.6	20	.8	875	1.4	1,000	2.7	1,740
1.0	190	1.7	30	.9	900	1.5	1,050	2.8	1,870
1.2	280	1.8	40	1.0	950	1.6	1,100	2.9	2,000
1.4	390	1.9	50	1.1	1,000	1.7	1,150	3.0	2,150
1.6	510	2.0	61	1.2	1,060	1.8	1,230	3.1	2,310
1.8	650	2.2	86	1.3	1,120	1.9	1,325	3.2	2,500
2.0	800	2.4	115	1.4	1,185	2.0	1,425	3.3	2,690
2.2	970	2.6	148	1.5	1,250	2.2	1,625	3.4	2,870
2.4	1,150	2.8	185	1.6	1,340	2.4	1,860	3.5	3,070
2.6	1,340	3.0	226	1.7	1,440	2.6	2,150	3.6	3,290
2.8	1,540	3.5	347	1.8	1,550	2.8	2,450	3.7	3,450
3.0	1,760	4.0	525	1.9	1,675	3.0	2,750	3.8	3,640
3.2	1,995	4.5	800	2.0	1,800	3.2	3,050	3.9	3,830
3.4	2,250	5.0	1,180	2.1	1,925	3.4	3,350	4.0	4,020
3.6	2,525	5.5	1,460	2.2	2,050	3.6	3,650	4.1	4,210
3.8	2,820	6.0	1,790	2.3	2,175	3.8	3,950	4.2	4,410
4.0	3,135	6.5	2,120	2.4	2,305	4.0	4,250	4.3	4,610
4.2	3,435	7.0	2,450	2.5	2,440	4.2	4,580	4.4	4,820
4.4	3,875	7.5	2,780	2.6	2,575	4.4	4,970	4.5	5,030
4.6	4,305	8.0	3,110	2.7	2,715	4.6	5,450	4.6	5,250
4.8	4,775	8.5	3,440	2.8	2,860	4.8	6,070	4.7	5,490
5.0	5,285	9.0	3,770	2.9	3,010	5.0	6,690	4.8	5,740
5.5	6,735	9.5	4,100	3.0	3,180	5.2	7,310	4.9	6,000
6.0	8,400	10.0	4,430	3.2	3,540	5.4	7,930	5.0	6,300
6.5	10,155	10.5	4,760	3.4	3,925	5.6	8,550	5.2	6,950
7.0	11,950	11.0	5,090	3.6	4,400	5.8	9,170	5.4	7,690
7.5	13,785	12.0	5,750	3.8	4,920	6.0	9,810	5.6	8,470
8.0	15,640	13.0	6,410	4.0	5,520	6.2	10,450	5.8	9,250
.....	.....	14.0	7,070	4.2	6,120	.....	.....	6.0	10,040

a Rating table for Bitterroot River.
b Rating table for Missoula River.

North Yakima.		Union Gap.		Kiona.		Spokane.		Gibbon.	
Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*
4.0	385	4.0	520	3.5	525	1.0	1,341	0.0	56
4.1	445	4.2	685	3.6	566	1.2	1,611	.1	65
4.2	505	4.4	885	3.7	612	1.4	1,897	.2	74
4.3	607	4.6	1,085	3.8	663	1.6	2,199	.3	83
4.4	709	4.8	1,315	3.9	719	1.8	2,517	.4	92
4.5	811	5.0	1,545	4.0	780	2.0	2,851	.5	106
4.6	913	5.2	1,775	4.2	916	2.5	3,754	.6	124
4.7	1,019	5.4	2,028	4.4	1,071	3.0	4,749	.7	146
4.8	1,132	5.6	2,320	4.6	1,245	3.5	5,832	.8	172
4.9	1,252	5.8	2,644	4.8	1,438	4.0	7,000	.9	202
5.0	1,380	6.0	3,000	5.0	1,650	4.5	8,245	1.0	233
5.1	1,515	6.2	3,388	5.2	1,878	5.0	9,565	1.2	298
5.2	1,658	6.4	3,808	5.4	2,122	5.5	10,957	1.4	372
5.3	1,808	6.6	4,258	5.6	2,383	6.0	12,416	1.6	454
5.4	1,966	6.8	4,738	5.8	2,665	6.5	13,941	1.8	544
5.5	2,131	7.0	5,250	6.0	2,965	7.0	15,525	2.0	642
5.6	2,304	7.2	5,793	6.5	3,780	7.5	17,160	2.2	748
5.7	2,484	7.4	6,365	7.0	4,695	8.0	18,845	2.4	862
5.8	2,672	7.6	6,969	7.5	5,708	8.5	20,577	2.6	984
5.9	2,867	7.8	7,605	8.0	6,810	9.0	22,351	2.8	1,114
6.0	3,070	8.0	8,270	8.5	7,998	9.5	24,165	3.0	1,252
6.2	3,490	8.5	10,059	9.0	9,270	10.0	26,012	3.2	1,398
6.4	3,910	9.0	12,030	9.5	10,620	10.5	27,887	3.4	1,552
6.6	4,330	9.5	14,180	10.0	12,045	11.0	29,787	3.6	1,714
6.8	4,750	10.0	16,510	10.5	13,536	11.5	31,712	3.8	1,884
7.0	5,170	10.5	19,015	11.0	15,036	12.0	33,653	4.0	2,061
7.2	5,590	11.0	21,690	12.0	18,036	.....	.....	4.5	2,533
7.4	6,010	11.5	24,536	13.0	21,036	.....	.....	5.0	3,052
7.6	6,430	12.0	27,550	14.0	24,036	.....	.....	5.5	3,613
7.8	6,850	.....	.....	.....	.....	.....	.....	6.0	4,217

NORTHERN PACIFIC COAST DRAINAGE.

In this division are included measurements on streams flowing into the Pacific north of the Columbia River. The river stations so far as established have been located within what is known as the Olympic Peninsula, the work being under the charge of Mr. W. J. Ware, of Port Angeles.

DESCRIPTION OF RIVER STATIONS.

Seattle station on Cedar River.—This station, described on pages 501–502 of the Nineteenth Annual Report, Part IV, was maintained by Mr. T. A. Noble for the Seattle Power Company. A description of the methods employed, with the results of discharge measurements, and diagrams, are published in an article by T. A. Noble, in the transactions of the American Society of Civil Engineers, Volume XLI, June, 1899. The station was discontinued September 30, 1898, and observations begun at Vaughns Bridge, about 3,000 feet below the outlet of Cedar Lake, or 15 miles above the station at Cliffords Bridge.

Seguin station on Dungeness River.—Described on page 182 of Paper No. 16; results given on page 503 of the Nineteenth Annual Report, Part IV. On July 29, 1898, the station was moved to a bridge about 8½ miles downstream, this being about a mile above the mouth. This bridge crosses the river diagonally, its northern end being about 15 degrees upstream from a position perpendicular to the current. The initial point and bench mark is the inner edge or corner of the first post for the covering of bridge on the south end and east side of bridge. The rod is horizontal and the zero is 25.91 feet from the initial point; distance of pulley from zero on rod is 4.90 feet; length of wire from end of ring to end of weight, 26.04 feet. The station was changed from the fact that measurements could be taken at the lower bridge much more accurately. At the upper bridge there was a slough, and the water running through that could not be accounted for. Since the station has been moved Henry McAlmond has been observer.

McDonald station on Elwha River.—Described on page 183 of Paper No. 16; results for 1897 given on page 505 of the Nineteenth Annual Report, Part IV.

Forks station on Calowa River.—Described on page 184 of Paper No. 16. The observer, until August 25, 1898, was George W. Eaton; since that date, Miss Irma Whittier, deputy postmaster at Forks.

Quillayute station on Solduck River.—Described on page 184 of Paper No. 16.

TABLES OF DAILY GAGE HEIGHT.

Daily discharge in cubic feet per second of Cedar River, near Seattle, Washington, for 1895.

Day.	Sept.	Oct.	Nov.	Dec.	Day.	Sept.	Oct.	Nov.	Dec.
1	.....	243	150	.....	18	174	163	163	836
2	.....	250	241	.....	19	178	165	155	788
3	.....	253	176	.....	20	217	161	128	735
4	.....	234	160	.....	21	200	157	174	695
5	.....	221	110	.....	22	208	153	155	669
6	.....	217	104	.....	23	260	152	144	855
7	.....	193	97	.....	24	356	152	138	802
8	.....	188	97	.....	25	438	166	125	786
9	.....	193	94	.....	26	382	152	125	731
10	.....	202	168	.....	27	337	152	236	1,355
11	.....	197	132	.....	28	315	146	241	1,355
12	.....	193	115	.....	29	291	148	152	1,329
13	182	186	115	2,176	30	262	144	180	.....
14	184	182	168	2,099	31	.....	138	.....	.....
15	188	178	165	1,687					
16	186	172	168	1,434	Mean	252	181	151	1,160
17	182	166	161	1,386					

Daily discharge in cubic feet per second of Cedar River, near Seattle, Washington, for 1896.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	1,023	766	1,766	786	1,191	2,002	1,901	315	202	170	745	757
2	892	743	1,381	768	1,285	1,675	1,371	347	197	178	784	1,172
3	828	751	1,256	743	1,163	1,434	1,329	228	195	190	920	2,165
4	828	758	1,079	721	1,144	1,363	1,308	390	193	188	836	3,601
5	1,355	1,228	845	715	1,116	1,371	1,265	320	188	180	790	3,623
6	1,867	1,285	811	684	1,181	1,410	1,219	313	182	170	764	3,395
7	2,034	1,329	792	659	1,107	1,426	1,237	306	180	.....	721	3,248
8	2,742	1,265	778	669	1,004	2,219	1,116	296	178	165	1,462	4,189
9	2,932	1,116	774	633	967	2,241	1,041	289	176	168	2,023	3,694
10	2,769	999	766	628	911	2,361	892	284	176	168	2,143	3,400
11	2,252	811	745	638	957	2,203	845	279	180	209	1,890	3,302
12	1,867	836	731	729	939	2,023	790	275	184	182	1,434	3,153
13	1,709	1,172	729	786	1,023	1,844	747	267	182	178	2,241	3,128
14	1,394	1,339	719	1,060	1,023	1,664	723	260	178	172	2,959	2,791
15	1,209	1,355	700	1,311	995	1,443	721	253	180	168	4,695	2,453
16	1,023	1,386	684	1,209	1,013	1,462	717	258	205	163	3,835	2,241
17	794	1,434	654	1,088	939	1,491	705	248	193	158	3,122	2,012
18	807	1,410	628	901	892	1,453	669	243	184	155	2,535	1,687
19	1,097	1,360	608	815	929	1,431	613	241	180	152	2,110	1,551
20	873	1,308	755	766	864	1,423	577	238	174	153	1,878	1,878
21	985	1,228	828	741	911	1,426	541	236	172	163	1,500	1,687
22	1,041	1,153	985	762	1,013	1,415	510	231	172	172	1,366	1,551
23	1,060	1,116	1,116	762	1,308	1,434	485	224	170	160	1,228	1,453
24	815	1,265	1,355	749	1,407	1,423	454	219	170	163	1,125	1,413
25	780	1,664	2,034	794	1,551	1,407	423	214	168	157	976	1,392
26	762	2,469	1,822	1,041	1,585	1,407	397	214	166	153	802	1,358
27	755	2,469	1,462	1,303	1,720	1,608	367	214	165	152	762	1,326
28	749	2,382	1,384	1,316	1,642	1,766	347	212	161	150	749	1,321
29	745	2,372	1,284	1,308	1,743	1,935	337	207	158	195	743	1,311
30	735	.....	1,032	1,237	1,901	1,732	330	202	157	212	723	1,265
31	727	.....	883	.....	2,029	.....	320	197	.....	221	.....	1,228
Mean	1,273	1,334	1,012	877	1,208	1,650	784	260	179	172	1,595	2,217

Daily discharge in cubic feet per second of Cedar River, near Seattle, Washington, for 1897.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	1,237	1,125	920	892	1,345	1,339	1,172	561	413	325	325	1,386
2	1,172	1,144	845	832	1,334	1,265	1,799	551	403	325	328	1,347
3	1,013	1,153	828	790	1,321	1,125	2,284	541	418	323	323	1,088
4	1,041	1,339	807	845	1,326	948	2,219	526	408	320	328	811
5	1,293	1,350	792	786	1,360	845	2,121	515	397	315	408	2,045
6	1,415	1,345	778	832	1,574	807	2,176	500	403	313	541	2,293
7	1,732	1,324	766	948	1,732	794	2,040	490	377	308	485	2,208
8	1,434	1,265	757	985	1,822	855	1,867	479	392	301	541	2,089
9	1,402	1,181	751	1,023	1,743	819	1,540	469	382	299	633	1,991
10	1,355	1,316	745	1,228	1,519	784	1,392	459	356	299	1,069	1,890
11	1,334	1,363	737	1,339	1,428	811	1,332	449	349	294	1,957	1,890
12	1,324	1,386	731	1,386	1,529	828	1,228	444	344	428	3,155	1,642
13	1,163	1,339	723	1,420	1,912	896	1,069	444	340	433	2,872	2,045
14	1,004	1,350	743	1,551	2,110	780	948	433	347	377	2,442	2,317
15	948	2,415	751	1,822	2,143	823	828	423	342	354	2,078	1,991
16	855	2,094	757	2,176	2,121	1,247	807	413	335	344	1,563	1,453
17	815	1,844	757	2,252	2,110	1,363	819	408	332	335	1,619	1,321
18	873	1,472	762	2,502	2,060	1,397	782	408	330	328	2,747	1,135
19	957	1,368	764	2,752	1,957	1,402	766	397	332	323	3,939	823
20	1,386	1,339	758	2,703	1,811	1,347	753	387	323	325	2,742	768
21	2,812	1,318	749	2,644	1,653	1,308	741	377	320	349	1,394	739
22	2,812	1,172	757	2,448	1,491	1,410	727	367	320	388	1,023	719
23	2,600	1,060	762	2,203	1,410	1,366	719	362	320	362	929	674
24	2,295	957	1,313	2,110	1,368	1,329	705	354	318	367	939	700
25	2,018	873	1,347	1,985	1,324	1,256	679	352	315	354	819	739
26	1,574	823	1,339	1,788	1,256	1,135	659	352	311	356	786	788
27	1,386	855	1,358	1,597	1,172	1,082	638	349	313	349	776	1,324
28	1,366	911	1,366	1,426	1,060	901	618	344	315	344	747	3,166
29	1,355	.....	1,316	1,366	939	823	597	344	320	337	695	3,601
30	1,345	.....	1,172	1,366	1,135	819	592	342	323	332	1,332	3,220
31	1,311	.....	976	.....	1,376	.....	572	392	.....	328	.....	2,622
Mean ..	1,440	1,303	901	1,599	1,562	1,060	1,135	427	350	340	1,318	1,639

Daily discharge in cubic feet per second of Cedar River, near Seattle, Washington, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.
1	2,214	449	731	474	1,004	780	510	152	.....
2	1,844	397	735	454	920	751	474	165	.....
3	1,415	423	751	438	957	770	449	168	.....
4	1,393	423	790	413	1,144	741	423	165	.....
5	1,324	721	729	397	1,284	786	397	160	.....
6	1,097	1,957	757	423	1,191	774	372	138	.....
7	1,004	1,529	760	526	1,097	1,004	352	152	.....
8	1,004	1,389	751	561	957	1,097	344	149	.....
9	864	1,376	721	551	828	1,191	323	143	95
10	807	1,191	731	536	794	1,144	315	136	.....
11	780	1,237	705	556	832	1,097	311	141	91
12	764	1,337	679	548	929	1,004	299	145	.....
13	731	1,363	679	613	864	911	291	.....	84
14	577	2,459	705	654	939	807	284	.....	.....
15	721	3,220	602	710	1,041	828	272	.....	78
16	654	3,318	551	715	1,191	794	255	.....	.....
17	679	2,785	474	723	1,350	780	274	.....	73
18	654	2,323	449	731	1,363	751	291	.....	.....
19	731	2,050	423	710	1,324	790	265	.....	71
20	741	1,402	526	679	1,191	770	255	.....	.....
21	751	1,368	500	654	1,004	780	243	.....	117
22	731	1,004	449	735	911	751	236	.....	.....
23	679	1,004	423	753	864	731	226	.....	207
24	628	864	449	770	807	705	219	.....	.....
25	602	760	449	828	790	679	207	.....	184
26	551	751	423	1,116	864	689	200	.....	.....
27	551	721	408	1,350	883	654	188	.....	214
28	526	745	433	1,337	1,004	577	184	.....	.....
29	500	.....	449	1,284	976	526	178	.....	219
30	449	.....	510	1,237	855	485	172	.....	.....
31	423	.....	474	.....	790	.....	165	.....	.....
Mean	850	1,377	587	716	998	802	289	151	130

Daily gage height, in feet, of Dungeness River at Seguin, Washington, for 1893.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	4.80	4.30	4.80	4.30	5.00	5.20	5.10	4.00	3.05	2.70	2.75	2.55
2	4.80	4.30	4.80	4.30	5.10	5.20	5.30	4.00	3.00	2.75	2.75	2.55
3	4.75	4.30	4.90	4.30	5.15	5.00	5.40	4.00	3.00	2.70	2.80	2.50
4	4.70	4.30	4.90	4.30	5.30	5.00	5.40	3.85	2.90	2.70	2.80	2.50
5	4.70	5.20	4.80	4.35	5.30	5.30	5.30	3.75	2.80	2.65	2.80	2.50
6	4.70	5.30	4.80	4.50	5.20	5.40	5.20	3.80	2.80	2.60	2.85	2.45
7	4.70	5.50	4.70	4.50	5.00	5.60	5.00	3.85	2.75	2.45	2.85	2.45
8	4.70	5.10	4.65	4.40	5.00	5.70	5.00	3.90	2.75	2.40	2.80	2.45
9	4.60	4.90	4.65	4.50	5.00	5.60	5.20	3.85	2.80	2.60	2.75	2.45
10	4.50	4.80	4.60	4.50	5.30	5.60	5.20	3.85	2.80	2.60	2.70	2.40
11	4.50	4.80	4.60	4.40	5.40	5.60	5.25	3.85	2.85	2.60	2.65	2.35
12	4.50	5.00	4.55	4.50	5.20	5.50	5.30	3.85	2.85	2.60	2.60	2.35
13	4.50	5.20	4.50	4.75	5.20	5.50	5.20	3.55	2.85	2.60	2.60	2.35
14	4.50	5.40	4.50	4.80	5.30	5.50	5.20	3.50	2.85	4.70	2.55	2.30
15	4.45	5.55	4.45	4.75	5.50	5.55	5.20	3.45	2.85	4.20	2.60	2.30
16	4.45	5.40	4.40	4.70	5.60	5.50	5.20	3.40	2.80	3.50	2.70	2.30
17	4.45	5.20	4.40	4.70	5.70	5.40	5.10	3.80	2.85	3.40	2.65	2.30
18	4.45	5.00	4.30	4.60	5.45	6.30	5.10	3.35	2.85	3.30	2.60	2.30
19	4.40	4.90	4.30	4.60	5.30	5.00	5.00	3.35	3.00	3.20	2.55	3.50
20	4.40	5.00	4.30	4.65	5.20	5.40	5.00	3.35	3.20	3.15	2.55	2.90
21	4.40	4.90	4.30	4.60	5.40	5.40	5.00	3.30	3.30	3.05	2.50	2.85
22	4.35	4.80	4.30	4.60	5.20	5.35	5.00	3.30	4.05	2.95	2.50	2.80
23	4.35	4.80	4.30	4.65	5.00	5.35	5.00	3.30	3.40	2.90	2.50	2.70
24	4.35	4.75	4.30	4.70	5.00	5.40	5.00	3.30	3.00	2.85	2.55	2.60
25	4.35	4.80	4.30	5.00	4.95	5.40	5.00	3.30	2.90	2.80	2.55	2.70
26	4.35	4.75	4.30	5.20	5.40	5.35	5.00	3.30	2.90	2.80	2.55	3.30
27	4.35	4.75	4.25	4.50	5.40	5.30	5.00	3.30	2.95	2.75	2.60	4.35
28	4.30	4.80	4.20	5.00	5.20	5.20	5.00	3.20	2.90	2.70	2.60	5.20
29	4.30	.....	4.20	5.00	5.20	5.20	4.05	3.15	2.85	2.70	2.60	4.45
30	4.30	.....	4.30	4.95	5.20	5.15	4.05	3.15	2.75	2.70	2.60	3.90
31	4.30	.....	4.30	.....	5.20	.....	4.15	3.10	.....	2.70	.....	3.70

Daily gage height, in feet, of Elwha River at McDonald, Washington, for 1893.

Date.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	4.80	1.90	2.58	1.60	2.55	2.74	3.20	2.25	1.54	1.66	2.44	2.00
2	3.65	1.85	2.57	1.62	2.52	2.66	3.20	2.35	1.54	1.51	2.62	1.92
3	3.52	1.99	2.46	1.65	2.53	2.54	3.41	2.50	1.49	1.40	2.22	1.81
4	3.33	1.93	2.85	1.66	3.15	2.68	3.15	2.47	1.42	1.42	2.28	1.75
5	3.20	4.44	2.80	1.70	3.10	3.02	2.61	2.41	1.39	1.40	2.22	1.75
6	3.20	4.38	2.49	1.72	3.07	3.56	2.54	2.36	1.38	1.40	2.21	1.62
7	3.18	4.45	2.41	1.95	3.01	3.70	2.50	2.30	1.45	1.31	2.12	1.53
8	3.18	4.42	2.35	1.99	2.10	3.91	2.52	2.25	1.46	1.29	1.80	1.52
9	2.61	3.00	2.32	2.48	2.58	4.01	2.60	2.45	1.49	1.28	1.81	1.51
10	2.37	2.96	2.26	2.39	3.00	4.06	2.65	2.47	1.47	1.20	1.78	1.51
11	2.60	4.12	2.15	1.91	2.90	3.68	2.75	2.46	1.47	1.22	1.70	1.47
12	2.32	3.97	2.39	1.88	3.21	3.52	3.18	2.19	1.48	1.35	1.67	1.46
13	2.22	4.26	2.33	2.10	3.00	3.50	2.85	2.17	1.45	3.50	1.64	1.45
14	2.19	4.15	2.29	2.15	3.01	3.42	2.78	2.15	1.42	4.50	1.62	1.46
15	2.20	5.12	2.15	2.17	3.58	3.40	2.65	2.12	1.40	3.10	1.60	1.48
16	2.16	4.91	2.10	2.16	3.78	4.04	2.61	1.98	1.43	2.40	1.75	1.54
17	2.13	3.59	2.02	2.15	3.97	3.74	3.60	1.90	1.44	2.31	1.80	1.59
18	2.20	3.45	1.95	2.00	3.40	4.10	3.10	1.90	1.44	2.10	2.10	1.64
19	2.65	3.17	1.99	1.90	3.31	5.15	2.90	1.87	1.47	2.00	1.98	2.82
20	2.61	3.40	2.00	1.85	2.99	3.80	2.80	1.97	1.63	1.90	1.78	2.45
21	2.60	3.20	1.90	1.80	3.54	3.33	2.15	1.94	2.47	1.90	1.78	1.99
22	2.28	3.15	1.85	2.28	2.15	3.20	2.90	1.92	3.18	1.87	1.77	1.96
23	2.10	3.00	2.00	2.22	2.80	3.15	2.30	1.90	2.12	1.70	1.70	1.92
24	2.08	2.70	1.95	2.24	2.60	3.02	2.35	1.87	1.95	1.65	1.70	1.90
25	1.90	2.60	1.85	3.25	3.84	3.05	2.45	1.90	1.52	1.56	1.79	1.95
26	1.80	2.55	1.80	2.61	3.55	3.00	2.41	1.84	1.43	1.57	1.72	5.20
27	1.75	2.58	1.74	2.52	3.60	3.10	2.40	1.83	1.39	1.59	2.20	4.95
28	1.78	2.60	1.69	2.45	3.50	2.98	2.35	1.58	1.45	1.62	2.24	4.70
29	2.00	.....	1.65	2.60	3.05	2.97	2.55	1.84	2.03	1.60	2.12	4.30
30	2.04	.....	1.65	2.62	2.95	2.92	2.60	1.82	1.69	1.71	2.50	3.18
31	1.90	.....	1.60	.....	2.76	.....	2.65	1.55	.....	1.68	.....	3.15

Daily gage height, in feet, of Calowa River at Forks, Washington, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	3.55	2.15	3.60	1.50	1.50	1.65	1.15	0.35	— .10	1.30	4.00	6.05
2	3.10	2.35	3.00	1.45	1.30	1.45	1.05	.30	— .10	1.05	3.40	5.85
3	3.25	2.60	3.85	1.25	1.05	1.15	1.02	1.50	— .10	1.04	5.80	3.65
4	2.90	2.85	3.40	1.10	1.20	.85	1.03	1.10	— .10	1.05	5.00	3.45
5	3.20	9.60	3.00	.80	1.35	1.35	1.00	1.11	— .10	1.00	4.30	3.00
6	3.20	7.80	2.75	.65	1.30	1.15	1.06	1.90	— .10	.90	4.40	2.85
7	3.00	7.65	2.40	1.65	1.15	.95	1.50	.50	— .10	.90	3.45	2.60
8	3.35	5.00	2.25	2.35	1.00	.80	1.20	.15	— .10	.80	3.05	2.40
9	3.00	5.25	2.35	5.30	1.45	.75	1.30	.14	— .10	1.00	2.75	2.25
10	2.70	5.85	1.80	4.25	1.30	.70	.30	.10	— .10	1.00	2.45	2.10
11	2.50	6.00	1.65	3.25	1.25	.65	.10	.13	— .10	1.60	2.20	1.90
12	2.35	6.75	2.35	2.65	1.10	.55	.20	.15	— .10	1.80	2.00	1.65
13	2.50	5.35	2.00	2.10	.90	.60	.10	.12	— .20	5.80	1.80	1.70
14	2.55	6.55	1.80	1.75	.85	.55	.10	.....	— .20	5.35	1.60	1.75
15	2.60	9.00	1.50	1.25	.80	.70	.20	.....	— .40	3.60	1.60	1.80
16	2.70	5.45	1.45	1.45	.70	1.10	.40	.....	— .40	2.70	1.60	1.85
17	2.80	4.35	1.30	1.85	.65	1.35	2.40	.....	— .40	2.45	3.00	1.60
18	3.45	3.80	1.25	1.60	.70	1.50	1.20	.....	— .40	2.20	3.25	1.60
19	5.50	3.35	1.20	1.35	.65	3.55	1.00	.....	— .40	1.85	1.80	5.40
20	5.15	3.10	1.75	1.15	.55	2.60	.80	.....	+2.00	1.80	2.65	4.00
21	3.90	4.40	1.45	1.50	.80	2.15	.60	.....	3.20	1.60	2.70	3.60
22	3.75	4.10	1.30	2.70	1.50	1.90	.30	.....	2.80	1.40	3.00	3.70
23	3.25	3.70	1.50	2.35	1.35	1.55	.10	.....	2.15	1.20	3.85	3.20
24	3.00	3.00	2.35	1.95	1.10	1.70	.45	.....	2.00	1.10	2.85	2.85
25	2.70	3.35	1.70	2.85	.90	1.60	.30	.....	1.40	1.00	3.00	4.85
26	2.00	2.60	1.40	3.10	1.35	1.35	.50	.00	1.00	2.05	3.05	7.90
27	1.85	3.85	1.35	2.65	1.20	1.60	.35	.00	1.20	2.40	4.60	9.20
28	2.00	4.50	1.85	2.25	1.15	1.35	.40	.00	1.80	2.20	4.85	8.00
29	2.30	.....	1.50	1.85	1.65	1.30	.55	—.10	2.20	1.80	5.10	7.20
30	2.55	.....	1.35	1.40	1.50	1.20	.35	.00	2.05	2.00	5.35	6.15
31	2.30	.....	1.20	.....	1.45	.....	.45	—.10	.....	2.00	.....	3.00

Daily gage height, in feet, of Solduck River at Quillayute, Washington, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	4.90	2.80	3.95	2.45	2.60	2.25	2.25	1.55	1.10	2.45	2.90	5.45
2	4.75	2.70	3.90	2.40	2.55	2.20	2.30	1.50	1.10	2.35	4.10	4.85
3	4.60	2.80	4.30	2.35	2.75	2.20	2.25	1.55	1.05	2.15	5.55	4.35
4	4.25	2.90	4.20	2.35	2.95	2.15	2.20	1.50	1.05	2.05	4.80	4.05
5	4.20	3.75	3.90	2.30	2.80	2.25	2.20	1.45	1.05	1.90	4.60	3.70
6	4.10	6.65	3.60	2.30	2.75	2.35	2.15	1.45	1.05	1.80	4.50	3.55
7	3.90	7.70	3.45	2.40	2.65	2.60	2.10	1.40	1.05	1.70	4.35	3.40
8	4.05	5.75	3.25	2.50	2.50	2.55	2.00	1.40	.95	1.65	3.80	3.25
9	3.75	5.60	3.15	3.95	2.50	2.60	1.95	1.40	.95	1.75	3.45	3.15
10	3.60	5.05	3.05	4.05	2.45	2.65	1.95	1.35	1.00	1.70	3.30	3.10
11	3.50	5.20	2.90	3.45	2.65	2.50	1.95	1.35	.95	2.15	3.10	3.00
12	3.30	6.50	2.95	3.20	2.60	2.40	2.00	1.35	.95	2.55	2.95	2.90
13	3.35	5.70	2.85	3.20	2.50	2.30	2.00	1.35	1.00	3.25	2.80	2.80
14	3.35	6.95	2.80	3.15	2.45	2.35	1.90	1.30	.95	7.45	2.65	2.65
15	3.30	7.40	2.70	3.05	2.60	2.60	1.85	1.25	.95	5.05	2.70	2.70
16	3.25	6.60	2.60	2.90	2.70	2.85	1.90	1.25	.95	3.80	2.90	2.75
17	3.40	5.55	2.50	2.75	2.70	2.50	2.30	1.25	.95	3.45	3.25	2.85
18	3.65	5.20	2.45	2.60	2.75	2.50	2.50	1.25	.95	3.30	4.10	2.80
19	4.50	4.60	2.40	2.50	2.55	3.90	2.30	1.35	1.00	3.10	3.80	5.55
20	4.35	5.80	2.50	2.40	2.70	3.20	1.95	1.30	1.15	2.90	3.55	4.80
21	3.90	5.20	2.40	2.45	2.75	2.85	1.90	1.30	2.05	2.75	3.45	4.25
22	3.95	4.80	2.40	2.80	3.00	2.70	1.80	1.30	2.60	2.60	3.95	4.10
23	3.60	4.60	2.30	2.75	2.70	2.65	1.70	1.25	3.05	2.45	4.05	3.75
24	3.40	4.35	2.65	2.70	2.40	2.65	1.65	1.25	2.40	2.30	3.80	3.55
25	3.25	4.35	2.50	3.20	2.50	2.70	1.65	1.20	1.90	2.25	3.50	3.70
26	3.25	4.25	2.35	3.25	2.55	2.50	1.60	1.20	1.70	2.45	3.75	6.35
27	3.10	4.00	2.50	3.30	2.65	2.40	1.65	1.15	1.80	2.70	4.05	6.85
28	3.05	4.05	2.65	3.10	2.50	2.35	1.60	1.15	1.55	2.80	4.35	7.30
29	2.90	.....	2.60	2.90	2.45	2.30	1.55	1.15	1.95	2.65	4.75	5.50
30	3.10	.....	2.55	2.75	2.40	2.25	1.60	1.15	2.85	2.50	5.10	4.70
31	2.95	.....	2.45	.....	2.30	.....	1.55	1.15	.....	2.65	.....	4.45

List of discharge measurements, 1898.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
				Feet.	*Sec.-feet.*
Jan. 18	Dungeness River	Seguin, Wash	A. J. Adams	4.45	242
Mar. 3	do	do	do		416
June 25	do	do	do	5.50	617
July 28	do	do	William J. Ware	5.10	336
July 29	do	do	do	4.05	327
Sept. 17	do	do	do	3.30	183
Oct. 15	do	do	do	4.00	453
Nov. 29	do	do	do	2.60	153
Dec. 24	do	do	do	2.60	157
Jan. 30	Elwha River	McDonald, Wash	A. J. Adams	1.74	1,092
Mar. 7	do	do	do	2.45	1,575
June 20	do	do	do	3.80	2,467
July 2	do	do	do	3.20	2,182
Aug. 20	do	do	William J. Ware	1.80	768
Oct. 25	do	do	do	1.56	557
Nov. 8	do	do	do	1.80	857
Dec. 9	do	do	do	1.51	622
June 30	Calowa River	Forks, Wash	A. J. Adams	1.20	467
Aug. 26	do	do	William J. Ware	.00	131
Dec. 19	do	do	do	5.40	3,204
June 29	Solduck River	Quillayute, Wash	A. J. Adams	2.25	823
Aug. 27	do	do	William J. Ware	1.15	289
Dec. 19	do	do	do	5.55	3,160

Rating tables.

Seguin. *a*		Seguin. *b*		Seguin. *c*		McDonald.		Forks.		Quillayute.	
Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage h'g't.	Discharge.
Feet.	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*
4.0	110	4.0	213	2.6	155	1.0	250	—0.4	40	1.0	220
4.1	125	4.1	220	2.7	156	1.1	290	— .2	80	1.2	312
4.2	138	4.2	227	2.8	157	1.2	330	.0	130	1.4	404
4.3	157	4.3	234	2.9	161	1.3	400	.2	180	1.6	500
4.4	177	4.4	241	3.0	165	1.4	470	.4	230	1.8	600
4.5	203	4.5	248	3.1	170	1.5	575	.6	286	2.0	700
4.6	234	4.6	255	3.2	175	1.6	687	.8	348	2.2	810
4.7	285	4.7	262	3.3	183	1.7	799	1.0	410	2.4	920
4.8	361	4.8	273	3.4	194	1.8	911	1.2	474	2.6	1,035
4.9	438	4.9	288	3.5	211	1.9	1,025	1.4	538	2.8	1,155
5.0	515	5.0	310	3.6	233	2.0	1,150	1.6	604	3.0	1,275
5.1	592	5.1	336	3.7	260	2.2	1,397	1.8	672	3.2	1,397
5.2	669	5.2	406	3.8	295	2.4	1,525	2.0	740	3.4	1,519
5.3	746	5.3	476	3.9	390	2.6	1,675	2.2	816	3.6	1,644
5.4	823	5.4	546	4.0	365	2.8	1,825	2.4	892	3.8	1,772
5.5	900	5.5	617	4.1	400	3.0	1,975	2.6	974	4.0	1,900
5.6	979	5.6	687	4.2	435	3.2	2,113	2.8	1,062	4.2	2,046
5.7	1,058	5.7	757	4.3	470	3.4	2,251	3.0	1,150	4.4	2,192
5.8	1,137	5.8	827	4.4	505	3.6	2,393	3.2	1,254	4.6	2,346
5.9	1,216	5.9	897	4.5	540	3.8	2,509	3.4	1,358	4.8	2,508
6.0	1,295	6.0	967	4.6	575	4.0	2,635	3.6	1,472	5.0	2,670
6.2	1,453	6.1	1,037	4.7	610	4.2	2,748	3.8	1,596	5.2	2,846
6.4	1,611	6.2	1,107	4.8	645	4.4	2,861	4.0	1,720	5.4	3,022
6.6	1,769	6.3	1,177	4.9	680	4.6	2,974	4.5	2,110	5.6	3,214
6.8	1,927	6.4	1,247	5.0	715	4.8	3,087	5.0	2,620	5.8	3,422
7.0	2,085	6.5	1,317	.....	.....	5.0	3,200	5.5	3,400	6.0	3,630
7.2	2,243	.....	.....	.....	.....	6.0	3,750	6.0	4,080	6.2	3,838
7.4	2,401	.....	.....	.....	.....	7.0	4,220	7.0	5,440	6.4	4,046
7.6	2,559	.....	.....	.....	.....	8.0	4,625	8.0	6,800	6.6	4,254
7.8	2,717	.....	.....	.....	.....	.....	.....	9.0	8,160	6.8	4,462

a Applicable from July 5 to December 31, 1897.
b Applicable from January 1 to July 28, 1898.
c Applicable from July 29 to December 31, 1898.

SAN FRANCISCO BAY DRAINAGE.

DESCRIPTION OF RIVER STATIONS.

Jelleys Ferry station on Sacramento River.—Described on page 185 of Paper No. 16; results for 1897 given on page 509 of the Nineteenth Annual Report, Part IV. During the year 1898 Mr. Fred Lemstrom has been furnished with a meter and has made at least two measurements a month of the river, or as often as any radical change occurred in the volume of the stream. He was furnished with Price's acoustic meter No. 12, which he used until the 1st of June. This was the only meter available during the first portion of the year for this work; subsequent to the 1st of June he was furnished with a large Price electric meter (No. 67). Observations with the acoustic meter were made, where practicable, at six-tenths depth, to determine the mean velocity of the stream; because of the depth of the river this could not always be done. With the larger meter top, middle, and bottom velocity are always taken. As previously described, the discharge measurements are made from a boat held by the cable. The rating curve for the year 1898 indicates that the river is deepening its bed. A rapid occurs about one-half mile below the gaging station. Observations were taken of river heights twice each day throughout the year. The discharge measurements, shown on page 185, were made in 1898 by Fred Lemstrom.

Oakdale station on Stanislaus River.—Described on page 187 of Paper No. 16, and also on page 510 of the Nineteenth Annual Report, Part IV; was located until July 30, 1898, at the wagon bridge one-half mile north of the town of Oakdale, California. One gage rod is set between the south or left-hand piers of the wagon bridge on the side toward the water, and can be read from the bridge. The datum is 27.92 feet below the top of the southeast iron pier of the wagon bridge. A rod for lowest readings of the river is 125 feet below the wagon bridge on the left bank and referred to the same datum. A secondary gage for determining the slope of the river is attached to the crib abutment of the Southern Pacific railroad bridge, 1,071 feet below the wagon bridge and referred to the same datum as the upper gage. Its zero is 5.92 feet below the top of the cap on the piles of the south crib pier of the railroad bridge. The pier has settled during the last year. The channel of the river is uniform and straight above and below the station, and both banks are high enough to prevent overflow in all except extreme conditions of flood. The bed of the stream at this point is of sand and gravel and changes only slightly.

The observer until May 4 was Walter Beistle; since then J. W. Bell has been observing on the river, and has reported the daily water height of the river at this point. Soundings were taken twice each month to determine the area of the cross section of the

stream, the intention being to determine the relation between the discharge in volume and area of cross section of the stream, and to use these elements in case the relation between the height of water on gage rod and volume discharged was not satisfactory. The point from which the measurements were made up to July, 1898, was the wagon bridge, 1,071 feet above the railroad bridge. This wagon bridge is nearly 60 feet above the surface of the water, consequently measurements were not as satisfactory as desired. On July 30, 1898, a cable was stretched across the river, 1,000 feet below the railroad bridge, at J. W. Bell's ranch house. The section at this point is relatively satisfactory, there being a stretch of straight river for 1,000 feet above and below the cable. Sand bars, however, are a constant objection to all points on the river, shifting their position with the changing seasons. In order to have the gage rod near the house of Mr. Bell, who is the observer, and also because of contemplated repairs on the railroad bridge to which the old gage was attached, on July 30, 1898, the gage was moved from the south pier of the railroad bridge to a point on the left bank of the stream, 250 feet above the cable and at the side of Mr. Bell's peach orchard; subsequent to this date all observations were taken on this gage. Two rating tables are therefore given for this stream, one prior and one subsequent to July 30, 1898.

As has been stated in previous reports, there are many diversions on the Stanislaus River above Oakdale, the principal one of which is by the Stanislaus and San Joaquin Valley Water Company. The water of the river is diverted on the right bank by this company, in a flume at a point 3 miles above Knights Ferry. A straight section of the flume, known as section 3, was selected, and by turning into it varying amounts of water a complete rating was obtained on June 1, 1898. Mr. J. Y. Beveridge, of Knights Ferry, California, who is the superintendent of the canal, has very kindly furnished the Geological Survey, since the 1st of June, with the daily depth of the water in the canal, from which the volume has been determined. A peculiarity about the rating table for this canal is that the gage height given is the distance down from a fixed point to the water surface. The water carries so much silt from the gold stamp mills above that a gage rod becomes quickly covered with slime, preventing an accurate reading of it. In the column marked "Gage heights," the less the difference given the greater is the corresponding discharge. The rating table for the Stanislaus River indicates that the bed is filling and rising, which is what might have been anticipated, because of the large gold-mining operations which are being carried on above. The discharge measurements, given on page 185, were made in 1898 by J. B. Lippincott.

Lagrange station on Tuolumne River.—Described on page 188 of Paper No. 16; results for 1897 on page 512 of the Nineteenth Annual

Report, Part IV; is located at the bridge in the town of Lagrange, California, 32 miles from Modesto. Observations have been taken daily on the vertical gage rod, which is fastened to timbers between the two iron piers on the right bank of the river. The bench mark is a nail driven into the bottom of the west post of the fifth bent south of the south iron cylinder, and is 15.31 feet above the zero of the rod. The channel, both above and below the bridge, is straight for several hundred feet, and the velocity of the stream is quite uniform. Both banks are high and not subject to overflow. The bed is of gravel. The observer was Cleo Pereira until June 11, and has been Anna P. McGinn for the balance of the year. During the past year the Lagrange Ditch and Hydraulic Mining Company's Canal, which is commonly known as the Mining Company's Canal, which diverts water from the left bank 3 miles above the Lagrange dam, has continued carrying water to its full capacity throughout the year. This volume is approximately 1,200 miner's inches or 24 second-feet. Water from this canal is used for ground sluice mining on the left bank of the river. About one-fourth of this amount returns to the river above the bridge, the rest returning below the bridge. In the latter portion of the year the Turlock irrigation district succeeded in running a small volume of water through its irrigation canal, which diverts its supply from the left bank of the stream at the Lagrange Dam. The amount of this water has been very small, and has been used solely for puddling the banks of the canal and for testing the dams at certain reservoirs. The rating curve for this stream has remained the same for the year 1898 as for 1897. The list of discharge measurements, made by J. B. Lippincott, is given on page 185.

Modesto station on Tuolumne River.—Described on page 189 of Paper No. 16; is located one-half mile south of the depot and at the wagon-road bridge at Modesto, California. The observer is J. T. Reed. Daily observations of river heights have been obtained through the courtesy of William Hood, chief engineer of the Southern Pacific Company. They extend only to January 18, at which time the gage was removed and the station discontinued. This station was not satisfactory in establishing the relation between the volumes discharged and the height of water on the gage rod. Daily records of volume are kept at Lagrange, which is on the same stream 32 miles above, and therefore no measurements of volumes were taken at the Modesto station during the past year.

Herndon station on San Joaquin River.—Described on page 190 of Paper No. 16; results for 1897 given on page 514 of the Nineteenth Annual Report, Part IV; located at the wagon bridge about one-half mile north of Herndon and 12 miles north of Fresno, California, on the line of the Southern Pacific Company. The original gage consisted of a vertical rod fastened to the lower side of the south central railroad bridge pier. The water of this stream attacks the paint on the gage

rod to a peculiar extent. To avoid this inconvenience a new rod was placed above the old one and nailed to the upper portion of the bridge. A float acting in a box, by means of a copper wire passing over a roller, actuates an index which points to a gage height corresponding to the datum of the original rod. The bench mark is at the south end of the wagon-bridge trestle, on the west side, on a nail in a post, 0.2 of a foot above the ground, and marked by a B. M. cut in the post. This elevation shows the rod datum is 24.12 feet. A gage on the same datum is also painted on the southwest cylinder. The channel for 900 feet above and 3,000 feet below the bridge is straight and the water has a uniform velocity. The right bank is high, rocky, and steep. The bed of the stream is sandy and gravelly. The observer is G. G. Nelson. Daily observations of river heights have been made at this station throughout the year, and in addition soundings have been taken twice a month to determine the varying areas of cross section of the river. The station for the years 1896 and 1897 was peculiarly satisfactory, but during the year 1898 it has proved erratic. Measurements of volume during the past season indicate that a different rating curve should be used for 1898 than that used in 1897. The measurements taken during the year 1898 agree quite well within themselves, but differ from previous ones. An effort has been made in this case to establish the relation between areas of cross section and volumes discharged. The condition described above may be explained by the forming of sand bars below the gaging station. The rating curve indicates that the bed of the stream is rising. The discharge measurements, given on page 185, were made by J. B. Lippincott.

Red Mountain station on Kings River.—Described on page 191 of Paper No. 16; results for 1897 given on page 518 of the Nineteenth Annual Report, Part IV; located 15 miles east of Sanger, California, southwest of Red Mountain. The station is on what is called the "Lower section of No. 9" of the lumber flume. It is located at the mouth of the Kings River Canyon and above all diversions from the stream. Within a distance of 5 miles below this station the following canals are taken out: On the right bank, the Church Ditch, which has the prior right; the Fowler Switch Canal, and the Kingsburg Canal; and on the left bank the 76 Canal. The bed of the stream is of gravel and bowlders, and it has maintained its section well since the time it was established in 1896. Measurements made during the year 1898 indicate that the rating curve has not changed materially; a slight correction is made in it between the gage heights 6½ feet and 9½ feet. Daily observations of river heights have been taken throughout the past year by Mrs. Alice House, except during a period from September 18 to October 1, for which time values have been estimated. The discharge measurements, given on page 185, were made by J. B. Lippincott.

Kingsburg station on Kings River.—Described on page 192 of Paper

No. 16; results for 1897 given on page 520 of the Nineteenth Annual Report, Part IV; located on the Southern Pacific Company's bridge, approximately 1 mile south of Kingsburg, California. The water is deep and slow. The observer is Alf. Thompson, and daily gage heights during the past year have been furnished through the courtesy of William Hood, chief engineer of the Southern Pacific Company. The repeated efforts to establish some relation between heights of water on the gage and volumes discharged or areas of cross section to volumes discharged has failed. An investigation was made which showed that diversions from the river, which are made at a point about 2 miles below the gaging station, through certain head gates, materially affect the grade and section of the river at the railroad bridge. For these reasons it has been considered advisable to discontinue the effort to give daily tables of volumes discharged and to give only the heights of water on the gage and the individual measurements that have been made. The station is of interest and importance, owing to the extensive litigation over the waters of the stream, the principal diversions from it occurring above the gaging station, and also to the fact that return water from the San Joaquin Valley is beginning to manifest itself in the increased volume of this river between the upper and lower diversions.

As previously stated, the channel of the stream at this station is badly broken by the piers of the railroad bridge and of a wagon bridge which is immediately below. Because the section is so poor at this point, measurements of discharge have been taken during 1898 at a point known as "Clarks Bridge," which is approximately 2 miles above the railroad bridge and crosses with a single span. The water at Clarks Bridge is deep and in the low stages of the stream it has a very slow velocity. During the summer of 1898 this velocity has been so slow that the meter would not act, consequently the stream has been gaged at a point a short distance above the railroad bridge, where the observations of the meter were taken by wading. The rod readings corresponding with the measurements that were taken both at the Kingsburg railroad bridge, at Clarks Bridge, and at the intermediate station where wading occurred, all were taken at the Kingsburg railroad bridge. This station was considered of value because of the series of diversions of the water a short distance below for the irrigation districts around Hanford. As stated above, there is a considerable amount of return water in this Kings River, which in part supplied this lower demand.

"*First point of measurement*" *station on the Kern River.*—Continuous observations by means of an automatic recording apparatus have been maintained on this stream by the Kern County Land Company, and in addition measurements of volumes discharged have been made once a week by this company. These records have been furnished by the courtesy of Mr. Walter James, chief engineer.

TABLES OF DAILY GAGE HEIGHT.

Daily gage height, in feet, of Sacramento River at Jellys Ferry, California, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	5.90	5.70	11.50	6.00	5.90	7.30	5.40	5.10	5.00	5.10	5.10	5.55
2	5.90	5.80	10.00	6.00	5.90	7.50	5.40	5.10	5.00	5.10	5.10	5.40
3	5.90	5.80	9.10	6.00	5.80	7.10	5.30	5.10	5 00	5.30	5.20	5.35
4	5.90	6.00	8.70	6.00	5.80	7.00	5.30	5.00	5.00	5.30	5.20	5.30
5	5.90	6.10	8.30	6.00	5.80	6.70	5.30	5.00	5.00	5.30	5.20	5.30
6	5.95	8.10	8.10	6.05	5.70	6.60	5.30	5.00	5.00	5.30	5.10	5.30
7	6.00	11.50	7.80	6.30	5.60	6.40	5.30	5.00	5.00	5.20	5.10	5.30
8	6.00	12.10	7.70	6.20	5.60	6.30	5.30	5.00	5.00	5.20	5.10	5.20
9	6.00	9.80	7.60	6.20	5.50	6.20	5.30	5.00	5.00	5.20	5.10	5.20
10	5.90	8.40	7.50	6.20	5.50	6.10	5.20	5.00	5.00	5.20	5.10	5.20
11	5.80	8.10	7.30	6.20	5.50	6.10	5.20	5.00	5.00	5.20	5.10	5.20
12	5.80	7.80	7.30	6.10	5.50	6.00	5.20	5.00	5.00	5.10	5.10	5.20
13	5.80	7.50	6.90	6.10	5.50	5.90	5.20	5.00	5.00	5.10	5.10	5.20
14	5.80	7.40	6.90	6.20	5.50	5.90	5.20	5.00	5.00	5.10	5.10	5.25
15	5.80	7.30	6.80	6.30	5.60	5.90	5.20	5.00	5.00	5.10	5.10	5.30
16	5.80	7.40	6.70	6.30	5.80	5.80	5.20	5.00	5.00	5.10	5.10	5.30
17	5.80	7.30	6.60	6.30	5.90	5.80	5.20	5.00	5.00	5.10	5.10	5.30
18	5.80	7.00	6.60	6.30	6.10	5.80	5.20	5.00	5.00	5.10	5.10	5.30
19	5.80	7.00	6.60	6.20	6.00	5.80	5.20	5.00	5.00	5.10	5.30	5.40
20	5.80	6.70	6.50	6.15	5.90	5.70	5.20	5.00	5.00	5.10	5.40	5.75
21	5.80	8.00	6.40	6.15	6.00	5.70	5.10	5.00	5.00	5.10	5.30	5.65
22	5.80	7.80	6.40	6.10	7.60	5.60	5.10	5.00	5.00	5.10	5.30	5.45
23	5.80	7.00	6.30	6.10	6.60	5.60	5.10	5.00	5.00	5.20	5.30	5.40
24	5.80	7.90	6.30	6.10	6.20	5.60	5.10	5.00	5.00	5.30	5.30	5.30
25	5.80	9.70	6.20	6.10	6.20	5.50	5.10	5.00	5.00	5.30	5.20	5.30
26	5.70	8.90	6.20	6.30	6.10	5.50	5.10	5.00	5.00	5.30	5.20	5.30
27	5.70	11.10	6.20	6.20	6.00	5.50	5.10	5.00	5.10	5.20	5.20	5.30
28	5.70	15.20	6.10	6.10	7.60	5.50	5.10	5.00	5.10	5.15	5.35	5.30
29	5.70	.....	6.10	6.00	7.00	5.40	5.10	5.00	5.10	5.10	6.00	5.30
30	5.70	.....	6.10	6.00	6.60	5.40	5.10	5.00	5.10	5.10	6.15	5.30
31	5.70	.....	6.00	.....	6.40	.....	5.10	5.00	.....	5.10	.....	5.30

Daily gage height, in feet, of Stanislaus River at Oakdale, California, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	2.50	2.50	3.90	3.10	5.60	3.60	2.80	4.30	4.30	4.30	4.30	4.60
2	2.60	2.40	3.80	3.20	5.10	3.60	2.80	4.40	4.30	4.30	4.30	4.60
3	2.50	2.40	3.70	3.20	4.80	3.30	2.70	4.40	4.30	4.40	4.30	4.50
4	2.70	2.30	3.60	3.20	4.30	3.20	2.50	4.40	4.30	4.30	4.30	4.50
5	2.50	2.30	3.50	3.10	4.10	3.20	2.50	4.30	4.20	4.30	4.30	4.50
6	2.60	2.40	3.50	3.20	4.20	3.50	2.50	4.30	4.20	4.30	4.30	4.50
7	2.70	2.80	3.50	3.30	4.20	3.75	2.50	4.30	4.20	4.30	4.30	4.40
8	2.60	3.40	3.40	3.30	4.30	3.40	2.40	4.30	4.20	4.30	4.40	4.40
9	2.50	3.00	3.40	3.20	4.40	3.50	2.40	4.30	4.20	4.30	4.40	4.40
10	2.50	2.90	3.40	3.60	4.50	3.15	2.40	4.30	4.20	4.30	4.30	4.40
11	2.40	2.80	3.30	3.90	4.70	3.30	2.40	4.30	4.20	4.30	4.30	4.40
12	2.60	2.70	3.10	3.80	4.90	3.40	2.40	4.20	4.20	4.30	4.30	4.50
13	2.60	2.70	3.10	4.10	4.80	3.30	2.40	4.30	4.20	4.30	4.30	4.50
14	2.40	2.70	3.10	4.50	4.90	3.20	2.40	4.20	4.20	4.30	4.20	4.40
15	2.30	2.60	3.00	4.70	4.10	3.20	2.30	4.20	4.20	4.30	4.20	4.40
16	2.40	2.60	2.90	5.20	4.10	3.20	2.20	4.10	4.20	4.30	4.20	4.40
17	2.20	2.50	3.00	5.50	4.90	3.50	2.20	4.20	4.20	4.30	4.20	4.40
18	2.20	2.60	2.90	5.90	4.80	3.70	2.20	4.20	4.20	4.30	4.30	4.50
19	2.30	2.70	3.00	6.00	4.80	3.50	2.20	4.20	4.20	4.30	4.30	4.50
20	2.40	2 60	2.90	5.70	4.80	3.20	2.20	4.20	4.20	4.30	4.30	4.60
21	2.20	2.60	2.90	5.30	4.70	3.00	2.20	4.20	4.20	4.30	4.30	4.80
22	2.10	2.50	2.90	5.30	4.50	3.50	2.20	4.20	4.20	4.30	4.30	4.90
23	2.20	2.60	2.80	4.80	4.30	3.30	2.20	4.20	4.20	4.30	4.20	4.70
24	2.20	2.80	2.80	5.90	4.20	3.10	2.20	4.20	4.30	4.40	4.20	4.70
25	2.30	3.50	2.90	6.50	4.10	3.10	2.20	4.20	4.30	4.40	4.30	4.60
26	2.40	3.20	3.00	6.40	4.00	3.10	2.10	4.30	4.30	4.30	4.30	4.60
27	2.50	3.40	3.00	6.60	3.10	3.10	2.10	4.30	4.40	4.30	4.30	4.50
28	2.30	4.40	2.90	6.10	3.10	3.00	2.10	4.30	4.40	4.30	4.30	4.50
29	2.30	.....	2.80	5.90	3.90	3.00	2.10	4.30	4.30	4.30	4.30	4.50
30	2.40	.....	2.70	5.60	3.80	3.00	a4.30	4.30	4.30	4.30	4.30	4.40
31	2.50	.....	3.10	.....	3.70	.....	4.30	4.30	.....	4.30	.....	4.30

a New rod placed July 30, 1898.

Daily gage height, in feet, of Tuolumne River at Lagrange, California, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	4.80	4.50	5.80	5.50	6.85	5.90	5.00	3.90	3.90	3.65	3.55	4.75
2	4.80	4.50	5.80	5.50	6.70	5.90	4.80	3.90	3.90	3.80	3.50	4.60
3	4.80	4.50	5.60	5.50	6.60	5.80	4.80	3.90	3.80	3.90	3.55	4.25
4	4.80	4.50	5.50	5.40	6.60	5.80	4.80	4.00	3.60	3.80	3.60	4.10
5	4.80	4.80	5.50	5.45	6.40	5.90	4.70	3.90	3.10	3.70	3.55	4.00
6	4.70	4.80	5.50	5.55	6.40	6.20	4.60	3.90	3.10	3.70	3.55	4.00
7	5.00	4.70	5.50	5.85	6.40	6.40	4.50	3.90	3.10	3.70	3.40	3.90
8	4.80	5.70	5.50	5.75	6.60	6.25	4.50	3.90	3.10	3.70	3.25	3.90
9	4.80	5.20	5.50	5.45	6.90	6.10	4.50	3.90	3.00	3.70	3.20	3.80
10	4.80	5.00	5.80	5.80	7.30	6.00	4.50	3.85	3.00	3.70	3.20	3.75
11	4.70	5.00	5.50	6.10	7.50	6.20	4.50	3.90	3.00	3.70	3.20	3.70
12	4.70	5.00	5.30	6.15	7.40	6.20	4.50	3.90	3.00	3.70	3.20	3.65
13	4.70	5.00	5.30	6.50	7.40	6.20	4.40	3.95	3.00	3.70	3.20	3.75
14	4.70	5.00	5.30	6.70	7.40	6.20	4.50	3.90	3.00	3.60	3.30	3.70
15	4.70	5.10	5.20	6.85	7.40	6.20	4.50	3.90	3.00	3.60	3.30	3.65
16	4.70	5.00	5.10	6.85	7.70	6.30	4.40	3.90	3.00	3.60	3.30	3.40
17	4.70	5.20	5.30	7.05	7.30	6.20	4.40	3.90	3.00	3.60	3.35	3.70
18	4.70	5.20	5.20	7.00	7.20	6.10	4.40	3.90	3.00	3.55	3.35	3.75
19	4.70	5.00	5.00	7.05	7.30	6.00	4.30	3.90	3.00	3.50	3.35	3.75
20	4.60	5.00	5.00	7.10	7.20	5.90	4.20	3.85	3.00	3.50	3.35	3.80
21	4.60	5.00	5.00	6.80	7.20	5.80	4.20	3.90	3.10	3.50	3.40	4.55
22	4.60	5.00	5.00	6.65	7.40	5.60	4.10	3.90	3.10	3.50	3.45	5.80
23	4.60	5.00	5.10	6.40	6.20	5.50	4.20	3.90	3.10	3.50	3.50	5.60
24	4.60	5.00	5.10	8.00	6.20	5.40	4.10	3.80	3.10	3.50	3.60	4.50
25	4.50	6.00	5.20	8.00	6.20	5.30	4.10	3.80	3.30	3.45	3.80	4.40
26	4.50	5.50	5.30	8.00	6.80	5.30	4.00	3.80	3.30	3.45	3.85	4.20
27	4.50	5.50	5.40	7.85	6.70	5.30	4.10	3.80	3.40	3.45	3.75	4.20
28	4.50	6.00	5.30	7.70	6.50	5.30	4.00	3.80	3.50	3.40	3.70	4.20
29	4.50	.....	5.30	7.60	6.50	5.10	4.00	3.80	3.60	3.40	3.70	4.10
30	4.50	.....	5.30	6.95	6.10	5.00	4.00	3.80	3.60	3.45	3.70	4.10
31	4.50	.....	5.40	.....	5.90	.....	3.90	3.90	.....	3.50	.....	4.10

Daily gage height, in feet, of San Joaquin River at Herndon, California, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	3.17	3.08	3.25	3.42	4.96	4.29	4.00	3.00	2.58	3.17	2.58	2.50
2	3.08	3.08	3.33	3.46	4.96	4.79	3.92	3.00	2.58	3.17	2.58	2.83
3	3.08	3.08	3.21	3.50	5.08	4.54	3.58	3.00	2.58	3.08	2.58	2.83
4	3.08	3.08	3.21	3.46	4.71	4.46	3.50	3.00	2.50	3.04	2.58	2.67
5	3.00	2.92	3.17	3.42	4.71	4.42	3.50	3.00	2.50	2.92	2.58	2.58
6	3.00	3.00	3.37	3.46	4.50	4.54	3.50	3.00	2.50	2.92	2.58	2.58
7	3.00	3.25	3.37	3.62	4.46	4.87	3.50	3.00	2.50	2.92	2.58	2.58
8	3.08	3.75	3.42	3.62	4.62	4.96	3.67	2.92	2.50	2.92	2.58	2.58
9	3.08	3.54	3.42	3.58	4.71	4.79	3.58	2.92	2.50	2.92	2.58	2.58
10	3.08	3.33	3.50	3.83	4.83	4.62	3.62	2.83	2.50	2.92	2.50	2.50
11	3.08	3.29	3.62	3.83	5.46	4.42	3.54	2.83	2.42	2.92	2.50	2.50
12	3.00	3.17	3.33	4.21	5.87	4.58	3.50	2.83	2.42	2.83	2.50	2.42
13	2.92	3.17	3.33	4.29	5.71	4.87	3.50	2.83	2.42	2.83	2.50	2.42
14	3.00	3.17	3.25	4.67	5.46	4.87	3.42	2.83	2.42	2.92	2.50	2.42
15	3.00	3.17	3.33	4.96	5.38	4.79	3.42	2.83	2.42	2.83	2.50	2.42
16	3.08	3.17	3.33	5.04	5.25	4.70	3.42	2.83	2.33	2.83	2.50	2.42
17	3.00	3.25	3.33	5.04	4.92	4.96	3.42	2.83	2.33	2.92	2.50	2.42
18	3.00	3.17	3.29	5.17	4.92	5.21	3.30	2.83	2.33	2.92	2.50	2.42
19	3.00	3.17	3.25	5.37	4.92	5.08	3.16	2.83	2.33	2.83	2.50	2.50
20	3.00	3.25	3.25	5.54	4.83	4.96	3.17	2.75	2.33	2.83	2.50	2.50
21	3.00	3.25	3.17	5.58	4.66	4.96	3.08	2.75	2.33	2.83	2.50	2.50
22	3.08	3.17	3.17	4.96	4.50	4.70	3.08	2.75	2.33	2.75	2.50	3.54
23	3.08	3.17	3.17	5.00	4.50	4.58	3.08	2.75	2.33	2.75	2.50	3.17
24	3.08	3.25	3.17	5.25	4.50	4.33	3.00	2.58	2.33	2.75	2.50	2.96
25	3.00	3.33	3.17	5.33	4.50	4.25	3.00	2.58	2.33	2.75	2.50	2.83
26	3.00	3.37	3.25	6.17	4.75	4.25	3.00	2.58	2.33	2.75	2.50	2.75
27	3.00	3.50	3.25	6.13	5.33	4.29	3.00	2.58	2.46	2.67	2.50	2.67
28	3.00	3.25	3.25	6.04	5.25	4.46	3.00	2.58	4.12	2.67	2.50	2.67
29	3.08	.....	3.29	5.62	4.71	4.25	3.00	2.58	3.46	2.67	2.50	2.67
30	3.08	.....	3.33	5.25	4.62	4.00	2.92	2.58	3.37	2.58	2.50	2.67
31	3.08	.....	3.33	.....	4.37	.....	3.00	2.58	.....	2.58	.....	2.67

Daily gage height, in feet, of Kings River at Red Mountain, California, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	4.60	4.40	5.00	5.40	7.70	7.60	5.80	4.20	3.70	4.90	3.70	3.90
2	4.50	4.50	5.20	5.50	7.30	7.30	5.70	4.20	3.70	4.60	3.80	3.90
3	4.50	4.50	5.10	5.50	7.40	7.00	5.50	4.20	3.70	4.30	3.80	3.90
4	4.50	4.40	5.00	5.50	7.40	7.10	5.30	4.20	3.70	4.40	3.70	3.80
5	4.50	4.40	4.80	5.70	7.00	7.30	5.20	4.20	3.70	4.20	3.70	3.80
6	4.50	5.00	4.90	5.70	7.10	6.80	5.20	4.20	3.70	4.20	3.70	3.80
7	4.60	4.60	5.10	5.70	7.20	6.80	5.10	4.20	3.60	4.10	3.70	3.90
8	4.60	5.60	5.20	5.80	7.50	6.50	5.10	4.10	3.60	4.10	3.70	3.90
9	4.70	5.20	5.20	6.20	8.10	6.50	5.10	4.10	3.60	4.00	3.70	3.90
10	4.60	5.00	5.20	6.60	8.70	6.40	5.10	4.10	3.60	4.10	3.70	3.80
11	4.50	5.00	5.60	6.70	9.00	6.40	5.00	4.10	3.60	3.90	3.70	3.80
12	4.60	4.90	5.60	6.90	9.20	6.40	4.90	4.00	3.50	3.90	3.70	3.60
13	4.50	4.90	5.50	7.10	8.70	6.70	4.90	4.00	3.50	3.90	3.70	3.60
14	4.50	4.90	5.30	7.60	8.10	6.80	4.90	4.00	3.50	3.90	3.70	3.60
15	4.50	4.80	5.20	8.20	7.70	6.80	4.80	4.00	3.50	3.90	3.70	3.70
16	4.50	4.90	5.30	8.30	7.70	7.00	4.70	4.00	3.50	3.90	3.70	3.70
17	4.50	4.90	5.20	8.30	7.70	7.30	4.70	4.00	3.50	3.90	3.70	3.70
18	4.50	4.90	5.20	8.50	8.10	7.30	4.70	4.00	a3.50	3.90	3.70	3.70
19	4.50	4.90	5.00	8.70	7.60	6.80	4.70	4.00	3.50	3.90	3.70	3.70
20	4.40	4.70	4.50	8.70	7.30	6.70	4.50	4.00	3.50	3.90	3.80	3.70
21	4.40	4.70	5.00	7.70	7.20	6.70	4.50	3.90	3.50	3.90	3.90	6.00
22	4.30	4.70	5.00	7.80	7.30	6.50	4.50	3.90	3.50	3.90	3.90	5.00
23	4.40	4.70	5.00	8.40	7.40	6.30	4.40	3.80	3.50	3.80	3.80	4.00
24	4.30	4.60	5.10	8.70	7.30	6.30	4.40	3.80	3.50	3.80	3.80	3.90
25	4.30	5.40	5.20	9.10	7.60	6.10	4.40	3.80	3.50	3.80	3.80	4.00
26	4.30	5.10	5.20	9.40	8.50	6.40	4.30	3.80	3.50	3.80	3.80	4.00
27	4.40	5.00	5.10	9.50	8.10	6.20	4.30	3.70	3.60	3.70	3.70	4.00
28	4.30	5.00	5.20	9.70	7.50	5.90	4.30	3.80	3.90	3.70	3.80	4.00
29	4.30	.....	5.40	8.70	7.10	5.90	4.30	3.80	4.50	3.70	3.80	4.00
30	4.30	.....	5.50	7.70	7.10	5.80	4.30	3.80	5.00	3.70	3.80	3.90
31	4.30	.....	5.50	.....	7.10	.....	4.30	3.80	.....	3.70	.....	3.80

a No observations from September 18 to October 1. Values in table have been estimated.

Daily gage height, in feet, of Kings River at Kingsburg, California, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	4.70	3.50	2.75	3.83	6.00	5.50	3.12	3.66	3.46	4.21	3.42	4.04
2	4.25	3.50	3.00	3.75	5.58	5.50	3.62	3.50	3.46	4.00	3.38	4.23
3	3.83	3.50	3.04	3.83	5.08	5.08	3.75	3.25	3.46	3.87	3.50	4.17
4	3.87	3.46	3.00	3.88	4.71	4.75	3.46	3.17	3.50	3.75	3.58	4.17
5	3.83	3.42	3.21	3.79	4.37	4.75	3.54	3.17	3.46	3.66	3.67	4.04
6	3.70	3.50	3.17	4.00	3.58	5.17	3.54	3.08	3.46	3.83	3.58	4.04
7	3.70	4.37	3.13	4.12	3.79	4.96	3.79	3.04	3.42	3.83	3.50	4.00
8	3.75	5.83	3.08	4.00	4.42	4.92	4.04	3.08	3.42	3.75	3.48	4.00
9	4.00	4.75	3.17	4.14	4.58	4.50	3.96	3.04	3.42	3.83	3.58	3.98
10	3.75	3.42	3.21	4.04	5.42	4.21	3.92	3.00	3.37	3.75	3.58	4.00
11	3.75	3.00	4.17	4.21	6.00	3.75	3.96	3.00	3.42	3.75	3.58	3.98
12	3.50	2.87	4.00	4.50	6.33	3.46	4.00	3.00	3.33	3.75	3.58	4.00
13	3.08	2.58	3.87	4.54	6.33	4.17	4.00	3.00	3.33	3.75	3.48	3.92
14	3.46	2.75	3.54	4.87	6.08	5.04	4.04	3.00	3.33	3.66	3.42	3.96
15	3.17	2.66	3.50	5.17	5.83	5.08	4.08	3.00	3.33	3.70	3.42	4.00
16	3.50	2.92	3.46	5.47	5.83	5.17	4.00	2.96	3.33	3.83	3.50	3.96
17	3.50	3.12	3.38	5.40	5.50	4.83	4.00	2.92	3.33	3.75	3.50	4.00
18	3.75	3.08	3.29	5.66	5.42	4.58	4.08	2.92	3.42	3.79	3.42	3.98
19	3.54	3.00	3.29	6.14	5.75	4.50	4.17	3.46	3.33	3.77	3.42	4.00
20	3.50	3.00	3.33	6.70	5.33	4.25	4.04	3.38	3.33	3.75	3.62	4.08
21	3.50	3.13	3.37	6.66	4.83	4.75	3.38	3.46	3.33	3.73	3.62	4.08
22	3.50	3.08	3.33	5.91	5.58	4.79	3.17	3.46	3.33	3.60	3.79	6.17
23	3.50	3.00	3.50	5.62	5.92	4.50	3.21	3.50	3.33	3.58	3.75	4.87
24	3.58	2.96	3.50	6.08	6.00	4.12	3.62	3.42	3.33	3.58	3.92	4.25
25	3.66	2.96	3.50	6.75	6.00	3.79	3.75	3.42	3.66	3.56	4.00	3.83
26	3.33	3.00	3.75	7.12	5.75	3.42	3.92	3.42	3.70	3.50	3.96	3.67
27	3.50	2.50	3.75	7.08	6.50	3.42	3.83	3.42	3.91	3.50	3.92	4.00
28	3.50	2.75	3.54	7.00	6.00	3.50	3.83	3.42	6.00	3.50	4.00	3.96
29	3.50	.....	3.66	6.83	5.58	3.25	3.83	3.42	5.08	3.50	4.00	3.92
30	3.50	.....	3.75	6.00	5.92	3.00	3.75	3.42	4.62	3.42	4.00	4.00
31	3.50	.....	3.75	.....	5.67	.....	3.71	3.42	.....	3.42	.....	4.00

List of discharge measurements, 1898.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
				Feet.	*Sec.-feet.*
Jan. 28	Sacramento River.	Jellys Ferry, Cal..	Fred Lemstrom ...	5.70	5,578
Feb. 21	.....do	.....do	.....do	8.30	13,118
Feb. 28	.....do	.....do	.....do	15.32	37,818
Mar. 13	.....do	.....do	.....do	6.95	9,495
Mar. 28	.....do	.....do	.....do	6.10	7,155
Apr. 13	.....do	.....do	.....do	6.10	7,216
Apr. 27	.....do	.....do	.....do	6.20	7,606
May 13	.....do	.....do	.....do	5.50	5,473
May 28	.....do	.....do	.....do	7.92	12,477
June 8	.....do	.....do	J. B. Lippincott ...	7.10	*a* 9,048
June 13	.....do	.....do	Fred Lemstrom ...	5.90	6,162
June 28	.....do	.....do	.....do	5.45	5,093
July 13	.....do	.....do	.....do	5.20	4,625
July 28	.....do	.....do	.....do	5.10	4,520
Aug. 13	.....do	.....do	.....do	5.00	4,324
Aug. 27	.....do	.....do	.....do	5.00	4,089
Sept. 13	.....do	.....do	.....do	5.00	4,160
Sept. 28	.....do	.....do	.....do	5.10	4,322
Oct. 13	.....do	.....do	.....do	5.10	4,380
Oct. 28	.....do	.....do	.....do	5.15	4,271
Nov. 28	.....do	.....do	.....do	5.20	4,662
Dec. 13	.....do	.....do	.....do	5.20	4,367
Apr. 17	Stanislaus River...	Oakdale, Cal	J. B. Lippincott ...	5.30	2,203
June 2	.....do	.....do	.....do	3.77	912
July 29	.....do	.....do	.....do	*b* 4.30	73
Oct. 6	.....do	.....do	.....do	4.20	50
Dec. 22	.....do	.....do	.....do	4.97	362
Apr. 18	Tuolumne River...	Lagrange, Cal.....	.....do	7.18	5,762
May 31	.....do	.....do	.....do	5.90	1,887
July 30	.....do	.....do	.....do	*c* 3.95	103
Sept. 9	.....do	.....do	.....do	3.00	0.00
Oct. 7	.....do	.....do	.....do	3.70	83
Apr. 19	San Joaquin River.	Herndon, Cal	.....do	5.42	4,162
May 30	.....do	.....do	.....do	4.58	2,235
July 28	.....do	.....do	.....do	3.00	611
Sept. 2	.....do	.....do	.....do	2.52	328
Dec. 20	.....do	.....do	.....do	2.50	287
Apr. 20	Kings River.....	Red Mountain, Cal.	.....do	8.55	4,943
May 29	.....do	.....do	.....do	7.14	2,672
July 27	.....do	.....do	.....do	4.32	503
Aug. 31	.....do	.....do	.....do	3.77	244
Dec. 21	.....do	.....do	.....do	7.00	2,444
Apr. 21	.....do	Kingsburg, Cal	.....do	6.58	*d* 1,658
Apr. 21	.....do	.....do	.....do	6.58	*d* 1,658
May 28	.....do	.....do	.....do	6.19	*e* 1,026
July 26	.....do	.....do	.....do	3.92	*d* 305
Do...	.....do	.....do	.....do	3.92	*e* 305
Aug. 30	.....do	.....do	.....do	3.42	*d* 94

a Using meter No. 67; using meter No. 12 the discharge was 9,290 second-feet.
b New rod; reading on old rod 2.10.
c On September 9 at gage height 3.00 the discharge stopped.
d S. P. R. R. Bridge.
e Clarks Bridge.

List of miscellaneous discharge measurements, 1898.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
				Feet.	*Sec.-feet.*
June 1	S. and S. J. V. Canal.	Knights Ferry	J. B. Lippincott ...	—2.39	24
Do...	.....do	.....do	.....do	—1.62	44
Do...	.....do	.....do	.....do	—1.12	61
Do...	.....do	.....do	.....do	—3.89	0
Oct. 5	.....do	.....	.....do	.....	38
July 10	North Fork of Kern River. *a*	"A" Channel	Frank H. Olmsted.	.....	17
Do...	.....do	"B" Channel.....	.....do	.....	199
Do...	.....do	"C" Channel.....	.....do	.....	107
Do...	.....do	"D" Channel.....	.....do	.....	8
Do...	.....do	Total	.....do	.....	331
Do...	South Fork *b*.....	.....	.....do	.....	13

a Above junction with South Fork.
b At a point 700 feet above junction with North Fork.

Rating tables.

Jellys Ferry.		Oakdale. *a*		Oakdale. *b*		Lagrange.		Herndon.		Red Mountain.	
Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height	Discharge.
Feet.	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*	*Feet.*	*Sec.-ft.*
5.0	4,250	2.1	74	4.2	50	3.0	.....	2.4	240	3.5	145
5.1	4,475	2.2	114	4.3	74	3.1	8	2.5	290	3.6	180
5.2	4,700	2.3	156	4.4	100	3.2	16	2.6	350	3.7	215
5.3	4,925	2.4	198	4.5	130	3.3	24	2.7	410	3.8	250
5.4	5,150	2.5	240	4.6	165	3.4	32	2.8	470	3.9	285
5.5	5,605	2.6	280	4.7	205	3.6	52	2.9	530	4.0	320
5.8	6,065	2.7	336	4.8	255	3.8	76	3.0	610	4.2	400
6.0	6,525	2.8	384	4.9	315	4.0	100	3.1	712	4.4	480
6.2	7,015	2.9	432	5.0	385	4.2	180	3.2	814	4.6	572
6.4	7,505	3.0	480	.....	.....	4.4	260	3.3	916	4.8	676
6.6	8,000	3.2	592	.....	.....	4.6	390	3.4	1,018	5.0	780
6.8	8,500	3.4	704	.....	.....	4.8	570	3.5	1,120	5.2	908
7.0	9,000	3.6	820	.....	.....	5.0	750	3.6	1,242	5.4	1,036
7.2	9,600	3.8	940	.....	.....	5.2	1,010	3.7	1,364	5.6	1,170
7.4	10,200	4.0	1,060	.....	.....	5.4	1,270	3.8	1,486	5.8	1,310
7.6	10,800	4.2	1,216	.....	.....	5.6	1,620	3.9	1,608	6.0	1,450
7.8	11,400	4.4	1,372	.....	.....	5.8	2,060	4.0	1,730	6.2	1,642
8.0	12,000	4.6	1,540	.....	.....	6.0	2,500	4.2	2,034	6.4	1,834
8.2	12,600	4.8	1,720	.....	.....	6.2	3,020	4.4	2,338	6.6	2,034
8.4	13,200	5.0	1,900	.....	.....	6.4	3,540	4.6	2,660	6.8	2,242
8.6	13,800	5.2	2,108	.....	.....	6.6	4,060	4.8	3,000	7.0	2,450
8.8	14,400	5.4	2,316	.....	.....	6.8	4,580	5.0	3,340	7.2	2,718
9.0	15,000	5.6	2,540	.....	.....	7.0	5,100	5.2	3,744	7.4	2,986
9.2	15,600	5.8	2,780	.....	.....	7.2	5,620	5.4	4,148	7.6	3,280
9.4	16,200	6.0	3,020	.....	.....	7.4	6,140	5.6	4,576	7.8	3,600
9.6	16,800	6.2	3,320	.....	.....	7.6	6,680	5.8	5,028	8.0	3,920
9.8	17,400	6.4	3,620	.....	.....	7.8	7,240	6.0	5,480	8.5	4,870
10.0	18,000	.....	.....	.....	.....	8.0	7,800	6.2	5,988	9.0	6,000
10.5	19,500	.....	.....	.....	.....	8.2	8,400	6.4	6,456	9.5	7,300
11.0	21,000	.....	.....	.....	.....	8.4	9,000	6.6	6,944	.....	.....

a Applicable from January 1 to July 29, 1898. Gage heights refer to old gage.
b Applicable from July 30 to December 31, 1898. Gage heights refer to new gage.

SOUTHERN CALIFORNIA DRAINAGE.

The river stations in southern California are under the charge of Mr. J. B. Lippincott, of Los Angeles. The streams are relatively small, and computations of discharge are based largely upon weir measurements and similar methods.

DESCRIPTION OF RIVER STATIONS.

Palmdale station on Littlerock Creek.—Described on page 193 of Paper No. 16; results for 1897 given on page 526 of the Nineteenth Annual Report, Part IV. The stream was dry from June 4 to the end of 1898. All of the water of the stream throughout the year has been diverted into the flume of the South Antelope Valley Irrigation Company at its headworks in the canyon. This water company has kept these records and furnished them without expense through the courtesy of Burt Cole, chief engineer. On January 4, 1898, a float measurement was made during low stage of water in Pallet Creek. The gage height was 0.52 and the discharge 0.78 second-feet. On the same date a measurement was made of Bigrock Creek opposite the dam site near Pallet Creek in Bigrock Creek. At that time the gage height was 5.70 and the discharge 5.27 second-feet. On this date also a current-meter measurement was made in the development tunnel on

Bigrock Creek, showing that the total developed water equals 1.33 second-feet. On February 20 a current-meter measurement was made by Burt Cole at the Littlerock Creek gaging station in the flume. The height of water was 2.76 feet and the discharge 5.11 second-feet. On March 2 a measurement above the head gate of the Littlerock Creek irrigation district showed there was flowing 2.02 second-feet. A float measurement of this water after flowing in the ditch for about a mile gave a discharge of 1.60 second-feet.

Azusa station on San Gabriel River.—Described on page 194 of Paper No. 16; results given on page 528 of the Nineteenth Annual Report, Part IV. No water was flowing from February 24 to March 9, also from March 11 to May 4, from May 6 to May 15, and from May 21 to the end of the year.

Daily observations have been made on the river by H. F. Parkinson, of Azusa, the superintendent in charge of the division of the water of this stream for all the companies diverting water at the mouth of the canyon. The entire output of the stream, practically, has been diverted into the canals of these companies and measured daily over weirs during 1898. A large number of separate diversions occur, and a number of weirs have been used in this computation. While these records have been kept in detail by Mr. Parkinson, it is considered unnecessary and confusing to give rating tables for all the weirs and the volumes diverted over each; herewith are given a table of gage heights and a rating table for the river at the gaging station, and a table showing the combined flow of the ditches for the period September 1 to December 31.

Unusual difficulties have been encountered in obtaining rating tables for the river rod. In 1897 the Vinelead irrigation district constructed a small diversion dam a short distance below the gage, which compelled its removal to a point higher up the stream. The rod was moved, and all readings for the first portion of 1898 were taken on this rod. During the summer of 1898 this rod was destroyed by unknown parties. In the fall of 1898 a final rod was placed at the same place as its immediate predecessor, and readings were taken thereon. Because of the extremely low rainfall there have been very few opportunities to rate these rods. A curve has been platted, in part from measurements and in part from comparative results of measurements on older rods. It is believed that this table is sufficiently accurate to give fairly good results for the small volumes of water that have passed these rods during the past year. A rating table is given for the Slaughter House tunnel on the Azusa Canal. A gage rod is located at the lower end of this tunnel, on the right-hand side of the conduit. During the ordinary low summer stages 0.7 of the entire volume of water supply passes this point, and the total diversions may be obtained from observations here. Prior to the completion of the weirs of the power company, described below, this was the point of measurement for the diverted waters of the stream.

The cable that was used in the past for the measurement of floods having become old and rusty, not being the property of the Geological Survey, and not being favorably situated for the measurements of floods, was abandoned. A new cable has been stretched across the river by the Geological Survey and a new car made at a point near the present gage rod in the main stream. The San Gabriel Electric Company during the past year has constructed a conduit of 4,000 inches capacity, diverting the water of the river at a point about six miles above the mouth of the canyon from the left bank of the stream and discharging it through a power house at the mouth of the canyon at a point below the gage rod in the river. Weirs have been constructed at the power house equal to the 4,000 inches, and if there is any excess water that the canal companies do not desire which is run through the power house by the electric company, it is wasted in the river below the gage; consequently a wholly new condition of affairs will exist during the year 1899 from that which existed during previous years. Arrangements have been made with the electric company by which they give access to their records, which are kept by automatic recording gages, both on the weirs at the power house and the weirs at the point of diversion. Mr. George Newman, chief engineer of this company, has shown the courtesy of offering this data without charge. This will result in a greatly improved record in the future. The discharge measurements shown on page 190 were made by J. B. Lippincott during 1898.

Warmsprings station on Santa Ana River.—Described on page 195 of Paper No. 16; results for 1897 given on page 567 of the Nineteenth Annual Report, Part IV. It is located 5 miles northeast of Mentone, California, three-fourths of a mile below the headworks of the Santa Ana Canal and opposite Warm Springs in the canyon. The gage is an inclined timber, the lower end of which has been set under the projecting edge of a large bowlder and fastened to upright posts at its upper end. On October 16, owing to some local legal conditions, an unusually large volume of water was turned into the Santa Ana Canal by the Bear Valley Company. This water was wasted from the canal at a point below the old gage rod. Every effort has been made to seek cooperation of the Bear Valley Company in perfecting the records of this stream, in order that they may be as accurate as it is possible to get them. This company has, however, declined to cooperate in this work, and refused to give the records of the amount diverted into their various canals. Individual measurements were made of these canals whenever a gaging was made of the stream itself. The only diversion above the gaging station is into the Santa Ana Canal, but it is probable that there was some fluctuation therein between the dates of measurements of its diversions. The above-mentioned conditions necessitated the establishment of a new gaging rod upon this stream at a point below where the waste from the canal

returned into the river. This was done on November 9, 1898, and since that date daily observations have been kept on the lower gage. This new gage is situated where the river flows at the foot of a granite cliff, about 800 feet below the mouth of Warm Springs Canyon and 100 feet above a road crossing the river. A vertical wooden gage rod has been bolted to the rock bluff which forms the left bank of the river. Since November 9, 1898, observations have been made on the new gage rod bolted to the cliff.

Mill Creek.—An effort has been made to obtain the daily records of flow of water in Mill Creek, but local companies have considered it against their interests to furnish these for publication. Individual measurements have been made of the stream at the head of the zanja, each time the Santa Ana was visited, and, owing to the absence of floods and the conditions of low water throughout southern California during the year 1898, these separate measurements may be taken as fairly representing the discharge of the stream.

TABLES OF DAILY GAGE HEIGHT.

Daily gage height, in feet, of Littlerock Creek at Palmdale, California, for 1898. (*a*)

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	Day.	Jan.	Feb.	Mar.	Apr.	May.	June.
1	0.35	0.40	0.38	0.42	0.31	0.20	17	0.40	0.40	0.39	0.39	0.56	.....
2	.35	.40	.38	.42	.27	.10	18	.40	.40	.38	.38	.53	.....
3	.35	.40	.38	.45	.27	.00	19	.40	.40	.39	.38	.48	.....
4	.35	.40	.38	.45	.25	.....	20	.40	.40	.40	.37	.47	.....
5	.35	.40	.38	.45	.26	.....	21	.40	.38	.40	.36	.41	.....
6	.35	.40	.38	.45	.35	.....	22	.40	.38	.40	.36	.42	.....
7	.35	.50	.38	.45	.33	.....	23	.40	.38	.38	.36	.38	.....
8	.40	.85	.38	.43	.32	.....	24	.40	.35	.38	.32	.37	.....
9	.40	.61	.38	.41	.32	.....	25	.40	.35	.38	.29	.34	.....
10	.40	.50	.40	.40	.28	.....	26	.40	.40	.40	.28	.31	.....
11	.40	.48	.42	.40	.26	.....	27	.40	.40	.40	.28	.29	.....
12	.40	.45	.40	.40	.24	.....	28	.40	.38	.40	.27	.27	.....
13	.40	.42	.38	.40	.22	.....	29	.40	.....	.41	.28	.25	.....
14	.40	.41	.39	.40	.22	.....	30	.40	.....	.42	.29	.22	.....
15	.50	.41	.39	.39	.24	.....	31	.40	.....	.41	.....	.20	.....
16	.40	.41	.39	.39	.72	.....							

a June 4 to December 31, dry.

Daily gage height, in feet, of San Gabriel River at Azusa, California, for 1898. (*a*)

[Below canal diversions.]

Day.	Jan.	Feb.	Mar.	May.	Day.	Jan.	Feb.	Mar.	May.
1	0.0	0.98	.....	.....	17	1.23	1.50	.....	1.03
2	.0	.98	.....	.....	18	1.22	1.05	.....	1.00
3	.0	.98	.....	.....	19	1.20	1.05	.....	1.02
4	.0	.98	.....	.....	20	1.19	1.05	.....	1.00
5	.0	.52	.....	1.08	21	1.18	1.04	.....	.....
6	.0	.52	.....	.0	22	1.18	1.03	.....	.....
7	.0	.52	.....	.0	23	1.17	1.00	.....	.....
8	.0	1.65	.....	.0	24	1.17	.....	.....	.....
9	1.40	1.50	.....	.0	25	1.17	.....	.....	.....
10	1.50	1.40	0.67	.0	26	1.17	.....	.....	.....
11	1.40	1.30	.....	.0	27	1.17	.....	.....	.....
12	1.36	1.15	.....	.0	28	1.17	.....	.....	.....
13	1.35	1.10	.....	.0	29	1.17	.....	.....	.....
14	1.34	1.05	.....	.0	30	1.17	.....	.....	.....
15	1.30	1.00	.....	1.90	31	.98	.....	.....	.....
16	1.28	1.50	.....	1.35					

a River dry from February 24 to March 9, from March 11 to May 4, May 6 to May 15, and from May 21 to end of year.

Daily discharge in cubic feet, per second, of San Gabriel Canals, measured over weirs near Azusa, California, 1898. (River dry.)

[Watershed 222 sq. mi.]

Date.	Sept.	Oct.	Nov.	Dec.	Date.	Sept.	Oct.	Nov.	Dec.
	Sec.-ft.	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*		*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*	*Sec.-ft.*
1	8.2	9.0	9.0	11.7	18	6.5	8.0	9.0	15.0
2	10.0	9.8	8.5	11.8	19	6.5	8.4	10.1	14.4
3	8.2	10.0	8.5	11.8	20	6.1	8.6	10.5	14.5
4	8.2	10.5	8.0	11.9	21	7.5	7.9	10.5	14.5
5	8.2	9.0	8.5	11.9	22	7.5	8.2	10.5	14.5
6	8.2	9.0	9.0	11.9	23	7.5	9.0	11.2	14.5
7	7.9	8.5	9.0	12.0	24	7.5	10.0	11.2	14.5
8	7.9	8.5	9.0	12.0	25	8.5	9.0	10.5	14.8
9	8.0	8.5	8.5	12.0	26	8.5	9.1	10.5	14.0
10	8.0	9.0	8.7	12.2	27	7.5	9.1	10.5	14.0
11	7.5	8.7	9.0	12.5	28	10.2	8.9	11.0	14.0
12	7.5	8.0	9.8	12.6	29	8.0	8.9	11.5	14.3
13	7.5	8.0	9.8	12.6	30	10.2	8.4	11.5	14.0
14	7.5	7.5	9.2	12.6	31	.....	8.4	.....	14.5
15	7.0	7.5	9.8	18.2					
16	7.0	7.5	9.8	15.2	Mean ...	7.8	8.7	9.8	13.5
17	6.7	8.0	9.8	15.0					

Daily gage height, in feet, of Santa Ana River at Warmsprings, California, for 1898.

Day.	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1	1.00	1.05	1.00	1.02	1.10	1.17	1.10	1.10	1.05	1.05	.....	2.1
2	1.00	1.05	1.00	1.02	1.10	1.15	1.12	1.10	1.05	1.00	.....	2.1
3	1.00	1.05	.97	1.00	.90	1.15	1.13	1.10	1.05	.90	.....	2.1
4	1.00	1.05	.95	1.00	.90	1.05	1.10	1.10	1.05	.90	.....	2.1
5	1.00	1.05	.95	1.00	.85	1.05	1.10	1.07	1.05	.90	.....	2.1
6	1.00	1.35	1.00	1.00	.85	1.15	1.10	1.05	.90	.85	.....	2.1
7	1.00	1.35	1.05	1.00	.85	1.15	1.07	1.00	.90	.80	.....	2.1
8	1.00	1.25	1.05	1.00	.85	1.10	1.07	1.10	.92	.80	.....	2.1
9	1.00	1.20	1.05	1.00	.95	1.10	1.07	1.20	1.10	1.00	.....	2.2
10	1.45	1.15	1.05	1.02	.95	1.15	1.15	1.25	1.15	1.00	2.1	2.1
11	1.15	1.15	1.03	1.00	1.40	1.15	1.15	1.25	1.15	.97	2.1	2.1
12	1.15	1.10	1.07	.91	1.40	1.10	1.22	1.22	1.15	.95	2.1	2.1
13	1.15	1.07	1.10	.91	1.30	1.10	1.20	1.20	1.12	.95	2.1	2.1
14	1.15	1.05	1.00	1.00	1.30	1.10	1.15	1.17	1.10	.95	2.1	2.1
15	1.10	1.05	1.03	1.02	1.60	1.05	1.15	1.15	1.05	.95	2.1	2.1
16	1.10	1.05	1.05	1.02	1.40	1.05	1.15	1.12	1.00	(*a*)	2.1	2.1
17	1.10	1.05	1.00	1.02	1.30	1.05	1.07	1.15	.95	.....	2.1	2.1
18	1.10	1.10	.90	.97	1.30	1.05	1.00	1.15	1.03	.....	2.1	2.1
19	1.10	1.05	.90	.97	1.25	1.05	1.00	1.15	1.07	.....	2.1	2.1
20	1.10	1.05	.87	.95	1.25	1.05	1.10	1.15	1.00	.....	2.3	2.1
21	1.10	1.05	1.00	.95	1.25	1.22	1.12	1.05	1.05	.....	2.2	2.1
22	1.15	1.00	.82	.92	1.25	1.25	1.12	1.05	1.05	.....	2.1	2.1
23	1.25	1.00	.82	.92	1.20	1.25	1.12	1.05	1.05	.....	2.1	2.1
24	1.10	1.00	.85	.92	1.20	1.25	1.12	1.00	1.05	.....	2.1	2.1
25	1.00	1.00	.90	.92	1.20	1.25	1.10	1.10	1.05	.....	2.1	2.1
26	1.00	1.00	1.05	.92	1.20	1.25	1.05	1.00	.92	.....	2.1	2.1
27	1.00	1.00	.95	.90	1.25	1.12	1.10	1.10	.95	.....	2.1	2.1
28	1.05	1.00	1.00	.90	1.25	1.12	1.10	1.00	1.00	.....	2.1	2.1
29	1.05	.....	1.00	.90	1.25	1.10	1.10	1.05	1.05	.....	3.1	2.1
30	1.05	.....	1.00	.90	1.25	1.10	1.10	1.05	1.05	.....	2.1	2.1
31	1.05	.....	1.02	.....	1.20	.....	1.10	1.05	.....	.....	.....	2.1

a Weir measurements were made from October 16 to November 9.

List of discharge measurements.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
1898.				*Feet.*	*Sec.-feet.*
Jan. 4	Pallet Creek	Palmdale, Cal	J. B. Lippincott	.....	*a* 0.78
Do.	Bigrock Creek	....do	....do	.....	*b* 5.27
Do.	....do	....do	....do	.....	*c* 1.33
Feb. 20	Littlerock Creek	....do	Burt Cole	0.39	*d* 5.11
Mar. 2	....do	....do	....do	.....	*e* 2.02
Do.	....do	....do	....do	.....	*f* 1.60
Jan. 12	San Gabriel River.	Azusa, Cal	J. B. Lippincott	1.36	23.29
Mar. 8	....do	....do	....do	.....	*g* 49.16

a Low stage of water.
b Opposite dam site near where Pallet Creek enters Bigrock Creek.
c In development tunnel, Bigrock Creek.
d Gaging in flume.
e Water above head gate, Littlerock Creek irrigation district, turned into head gate.
f Measurement of above water after traveling in ditch 1 mile.
g Total in canals.

List of discharge measurements—Continued.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
1896.				*Feet.*	*Sec.-feet.*
Apr. 2	San Gabriel River.	Azuza, Cal.	J. B. Lippincott		a41.00
May 17	do	do	do	1.03	15.40
July 21	do	Power Canal head.	do	4.06	13.21
Aug. 8	do	do	do	3.02	8.42
1897.					
Apr. 30	Azusa Canal.	Tunnel	J. A. Vogleson	2.70	55.00
Aug. 7	do	do	A. Q. Campbell	1.80	24.00
Sept. 1	do	do	do	1.58	18.00
Sept. 29	do	do	do	1.35	14.00
Nov. 13	do	do	do	1.54	20.00
Nov. 27	do	do	J. B. Lippincott	1.64	21.00
1898.					
Mar. 8	do	do	H. F. Crowe	2.28	37.00
Apr. 2	do	do	J. B. Lippincott	1.95	30.00
May 10	do	do	do	1.70	23.00
May 17	do	do	do	2.10	32.00
July 1	do	do	F. H. Olmsted		11.78
1897.					
Nov. 13	Duarte Canal	Below division box	A. Q. Campbell	.52	5.35
Nov. 27	do	do	J. B. Lippincott	.85	11.80
1898.					
Jan. 12	do	do	do	.675	8.25
Do.	do	do	do	.40	3.45
Do.	do	do	do	.275	1.81
Do.	do	do	do	.92	12.52
Mar. 8	do	do	H. F. Crowe	.79	12.30
Apr. 2	do	do	J. B. Lippincott	.84	11.30
May 17	do	do	do	.92	13.00
Jan. 8	Santa Ana River	Warmsprings, Cal.	do	1.00	25.56
Do.	Santa Ana Canal	do	do		8.72
Mar. 9	Santa Ana River	do	H. F. Crowe	1.05	43.78
Do.	Santa Ana Canal	do	do		7.04
Apr. 11	Santa Ana River	do	J. B. Lippincott	.97	31.61
Do.	Santa Ana Canal	do	do		7.67
Apr. 29	Santa Ana River	do	do	.90	29.67
Do.	Santa Ana Canal	do	do		8.00
June 12	Santa Ana River	do	do	1.10	35.14
Do.	Santa Ana Canal	do	do		8.92
July 23	Santa Ana River	do	do	1.10	42.22
Do.	Santa Ana Canal	do	do		5.84
Sept. 8	Santa Ana River	do	do	1.05	35.01
Do.	Santa Ana Canal	do	do		1.66
Oct. 18	Santa Ana River	do	F. H. Olmsted	.95	22.78
Do.	Santa Ana Canal	do	do		7.92
Nov. 9	Santa Ana River	do	do	b2.10	21.78
Dec. 8	do	do	do	b2.13	24.74

a Total in canals.
b New gage rod established on November 9 below discharge of Santa Ana Canal waste gate.

Rating tables.

Palmdale.		Azusa.		Azusa Canal Tunnel.		Warmsprings. a		Warmsprings. b	
Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.	Gage height.	Discharge.
Feet.	*Sec.-feet.*	*Feet.*	*Sec.-feet.*	*Feet.*	*Sec.-feet.*	*Feet.*	*Sec.-feet.*	*Feet.*	*Sec.-feet.*
0.0	0.0	0.4	0.0	1.0	9.0	0.80	25	2.10	22
.1	.5	.5	.2	1.1	10.6	.85	26	2.15	25
.2	2.0	.6	.5	1.2	12.2	.90	28	2.20	28
.3	4.0	.7	1.2	1.3	13.9	.95	30	2.25	31
.4	6.0	.8	3.0	1.4	15.8	1.00	33	2.30	34
.5	9.0	.9	6.0	1.5	17.8	1.05	36	2.35	38
.6	12.0	1.0	9.0	1.6	19.8	1.10	40	2.40	42
.8	19.0	1.1	13.0	1.7	22.0	1.15	45	.....	.....
1.0	27.0	1.2	17.0	1.8	24.3	1.20	51	.....	.....
1.2	35.0	1.3	21.0	1.9	26.9	1.25	58	.....	.....
1.4	44.0	1.4	26.0	2.0	29.5	1.30	66	.....	.....
1.6	54.0	1.5	31.0	2.1	32.5	1.35	76	.....	.....
1.8	64.0	1.6	38.0	2.2	35.6	1.40	87	.....	.....
2.0	75.0	1.7	45.0	2.3	39.0	1.45	99	.....	.....
2.2	86.0	1.8	53.0	2.4	42.8	1.50	112	.....	.....
2.4	96.0	1.9	63.0	2.5	46.6	1.55	129	.....	.....
2.6	108.0	2.0	80.0	2.6	50.8	1.60	149	.....	.....
2.8	120.0	.....	.....	2.7	55.2	.....	.....	.....	.....

a Applicable from January 1 to November 8, 1898.
b Applicable from November 9 to December 31, 1898.

List of miscellaneous discharge measurements (California), 1898.

Date.	Stream.	Locality.	Hydrographer.	Gage height.	Discharge.
				Feet.	*Sec.-feet.*
Aug. 24	San Gabriel River	Developed in Azusa tunnels.	J. B. Lippincott		.52
Do.	do	Pumped by Azusa at canyon mouth.	do		.30
Apr. 12	Mill Creek	Division box	J. B. Lippincott		15.73
Do.	Green Spot pipe line.		do		1.74
Apr. 29	do	Mill Creek	do		2.94
Do.	Mill Creek	Division box	do		b 18.88
Oct. 18	do	Crafton division box.	F. H. Olmsted		b 15.34
Nov. 9	do	Division box	do		15.20
Mar. 9	Santa Ana River	Weir at head of Highlands Canal.	H. F. Crowe		b 10.76
Do.	do	Flume near pressure box, Redlands Canal.	do		22.00
Apr. 29	Santa Ana Canal	Headworks	J. B. Lippincott		b 12.66
June 20	Santa Ana, south channel.	Narrows below Riverside.	F. H. Olmsted		37.00
Do.	Santa Ana, north channel.	do	do		11.00
	Total				48.00
Aug. 28	Santa Ana River	400 feet below Riverside Bridge.	do		3.85
Do.	do	Near head Roubidoux Ditch.	do		8.50
Aug. 29	do	Below Riverside, at Narrows.	do		8.06
Do.	do	do	do		31.00
Do.	do	Rincon Narrows	do		63.00
Aug. 30	do	Postierra Ditch	do		4.15
Oct. 18	do	Redlands Canal	do	.84	7.26
Do.	do	Head Highlands Ditch.	do		b 9.85
Do.	Head Green Spot pipe line.	Santa Ana	do		1.36
Nov. 9	Santa Ana River	Head Santa Ana Canal.	do		b 19.50
Do.	do	Redlands Canal in flume.	do		b 10.20
Do.	do	Head Green Spot pipe line.	do		.50
Do.	do	Head Highlands Ditch.	do		b 8.12
Dec. 8	do	Head Green Spot pipe line.	do		.50
Do.	do	Head Santa Ana Canal.	do		20.60
June 28	Los Angeles River	Bridge No. 2	J. B. Lippincott	.92	42.00
Do.	do	Main Supply Ditch	do	2.85	18.00
Apr. 29	Highland Canal, north fork.	Headworks	do		b 17.00
Do.	Redlands Canal	do	do		13.00
June 10	Lytle Creek	do	do		b 13.39
Do.	Rialto Canal	Weir	do		12.50
Do.	Grapeland Canal		do		.89
June 20	Narrows Ditch		F. H. Olmsted		3.75
July 28	Green Spot pipe line.	Headworks	J. B. Lippincott		2.20
Aug. 12	Castaic	Near mouth	F. H. Olmsted		(a)
Do.	Pacoima	Submerged dam	do		.20
Do.	Little Tejunga River.	Mouth	do		.05
Aug. 30	Chino Creek	Mains Rancho	do		4.95
Aug. 21	Tulare Lake	Tulare County	do		(a)

a Dry. b Weir.

LOW-WATER MEASUREMENTS.

The summer of 1898 has been one of very great drought throughout the State of California. Not only has the seasonal rainfall been very slight, but it is a culmination of a number of unusually dry years. During the past eight years the annual rainfall with but one exception has been below the average. Because of this shortage of water crop special efforts have been made during the months of August and September of 1898 to take measurements of the low water in numerous streams throughout the State upon which ordinarily no observations have been taken. These measurements can be accepted as representing the minimum flow of the streams upon which they were taken. The following is a list of the midsummer measurements:

Measurements of low-water stage in California during June, July, August, September, and October, 1898, by the United States Geological Survey.

Date.	Stream.	Locality.	Area of section.	Mean velocity.	Discharge.
			Sq. feet.		*Sec.-feet.*
June 2	Sacramento River.	Jellys Ferry	2,547.00	3.552	9,048.00
Sept. 13	....do	....do	1,802.00	2.3	4,152.00
Oct. 7	Yuba River	Dry, except for water from reservoir.			
Oct. 7	American River	North and Middle Fork, at head of North Fork Ditch.			16.00
Sept.—	....do	At Folsom			34.50
June 1	Stanislaus River	Oakdale	486.00	1.875	911.50
June 2	....do	Flume No. 3, Stanislaus and San Joaquin Canal.	24.10	3.00	72.35
July 29	....do	Oakdale	167.00	.435	72.80
Do.	....do	Stanislaus and San Joaquin Canal at Knights Ferry.			42.00
Oct. 6	....do	Oakdale	145.20	.342	49.60
Oct. 5	....do	Stanislaus and San Joaquin Canal.			33.40
Oct. 6	....do	....do			32.70
July 30	Tuolumne River	Lagrange	445.00	.232	103.20
Do.	....do	Mining Company Ditch			24.00
Oct. 7	....do	Lagrange	72.00	1.15	82.70
Do.	....do	Mining Ditch			24.00
Do.	....do	Turlock flume			30.00
	Total flow				136.70
July 28	San Joaquin River.	Herndon	665.00	.92	611.00
Sept. 2	....do	....do	520.00	.631	328.00
July 26	Kings River	Clarks Bridge	1,088.00	.28	305.00
July 25	....do	Kingsburg Railroad bridge	1,290.00	.236	305.00
July 27	....do	Red Mountain	452.00	1.13	508.00
Aug. 30	....do	Kingsburg Railroad bridge	191.70	.492	94.10
Aug. 31	....do	Red Mountain	333.50	.731	243.80
Do.	....do	Church Ditch, check near Trimmer Spring road.	104.40	1.58	164.30
Do.	....do	The 76 Ditch at mouth of canyon.			(a)
Do.	....do	Fowler Switch Canal at mouth of canyon.			(a)
Do.	....do	Kingsburg Ditch at mouth of canyon.			(a)
Sept. 1	Kaweah River	One-half mile above power company's headworks.	28.4	1.24	35.30
Do.	....do	Iron bridge	34.2	.523	17.90
Do.	....do	Irrigation and power ditch			8.50
Do.	....do	Pogues Ditch			4.50
Do.	....do	South Fork Kaweah, at junction.			(a)
Do.	....do	North Fork Kaweah, at junction.			.30
Do.	Tule River	Headworks Pioneer Ditch (estimated).			6.00

a Dry.

Measurements of low-water stage in California during June, July, August, September, and October, 1893, etc.—Continued.

Date.	Stream.	Locality.	Area of section.	Mean velocity.	Discharge.
			Sq. feet.		*Sec.-feet.*
June 20	Warm Creek	Meek and Daily Ditch headworks.	(a)		8.42
Do.	do	Stout Ditch, lot 4, block 60, San Bernardino Rancho.			2.30
Do.	do	McKensie Ditch	2.90	.87	2.54
Do.	do	Rabel Ditch, lot 2, block 60	(a)		5.67
Do.	do	Beam Ditch			.67
June 7	do	Haws & Talmage first ditch, one-half mile west of Harlem.	.9	1.00	.90
June 30	do	Upper canal, Riverside Water Company, at old Colton Mill.	(a)		69.46
Sept. 21	do	do	(a)		61.34
Do.	do	Daily flume			.63
Do.	do	McKensie Ditch			2.16
Do.	do	Hays & Talmage			(b)
Do.	do	Rabel Ditch, at headworks			3.07
Sept. 22	do	Shay Ditch			2.08
June 10	Lytle Creek	Rialto Canal, Anglo-American division, Canaigre Company.	5.292	2.027	10.73
	do	McIntyre Ditch			.28
	do	San Bernardino Domestic Reservoir.			1.95
June 29	do	Whitings Ditch			.30
June 27	do	800 feet below Mount Vernon Bridge.	(a)		.28
Aug. 27	do	Gatehouse, Canaigre Company.	(a)		10.01
Sept. 22	do	Whitings Ditch			.10
Do.	do	McIntyre Ditch			.04
Do.	do	Carter Ditch			.006
June 11	West Twin Creek	Tollhouse, Waterman Canyon	.92	2.31	2.12
Sept. 9	do	Estimated			.38
June 11	East Twin Creek	K. C. Syndicate, flume	2.33	.83	1.95
Do.	do	K. C. Syndicate, developed			.11
		Total			2.06
Sept. 7	do	K. C. Syndicate			.73
June 11	City Creek	Headworks in canyon	2.295	1.32	3.03
June 29	do	Longsden & Farrell Ditch	.878	.82	.723
Do.	do	Whitlock Ditch	.209	1.16	.244
Do.	do	Daley Ditch across City Creek	.396	1.56	.62
Sept. 9	do	Headworks in canyon	.36	.20	.07
Sept. 21	do	Longsden & Farrell Ditch			.63
June 12	Plunge Creek	Headworks	1.565	1.446	2.26
Sept. 9	do	Estimated			.20
June 12	Santa Ana River	Warm Springs	18.25	1.923	35.14
Do.	do	Head Santa Ana Canal			3.92
	do	Total at mouth of canyon			39.06
Do.	do	Head North Fork Canal	(a)		11.37
Do.	do	Green Spot pipe line			.63
Do.	do	Bolen Tunnel	.32		1.24
Do.	do	Head Redlands Canal			18.40
Do.	do	Morton Canyon			.12
July 23	do	River at Warm Spring	21.57	1.96	42.22
Do.	do	Santa Ana Canal	(a)		5.34
	do	Total at mouth of canyon			47.56
Do.	do	Green Spot pipe line	(a)		2.2
Do.	do	Redlands Canal			15.0
June 29	do	Head Gage Canal in Santa Ana River.	(a)		1.16
Do.	do	Timber Ditch			(b)
June 30	do	Rice & Thorn flume, artesian			11.09
Do.	do	Below Ward & Warren Ditch			7.84
Do.	do	Diverted into W. & W. Ditch			.72
June 17	do	"A" + 1, one-half mile below S. C. R. bridge, Riverside to Colton.	6.19	1.57	9.742

a Weir. b Dry.

Measurements of low-water stage in California during June, July, August, September, and October, 1898, etc.—Continued.

Date.	Stream.	Locality.	Area of section.	Mean velocity.	Discharge.
			Sq. feet.		*Sec.-feet.*
June 17	Santa Ana River..	Riverside Water Co. Ditch, left bank, 2 miles below S. C. R. bridge, Riverside to Colton, 4 p. m.	2.773	3.35	9.27
Do.	.....do.....	Same station, 10 a. m.....	2.905	3.88	11.27
June 18	.....do.....	Jurupa Ditch at Agua Mansa.	6.39	2.16	13.83
June 19	.....do.....	Spring Brook "D," below Roubidoux hill.	1.10	2.65	2.92
Do.	.....do.....	"E" Ditch, right bank, one-half mile below Riverside bridge.	4.72	1.21	5.68
Do.	.....do.....	Roubidoux Ditch, near division "F."	4.28	2.08	8.94
Do.	.....do.....	River in Narrows, 4 miles below Riverside.	31.91	1.49	47.63
Do.	.....do.....	"H" Ditch, 5 miles below bridge, right bank.	3.04	1.23	3.75
Do.	.....do.....	"J" Griffith's place, right bank.	8.35	1.20	9.99
June 20	.....do.....	Ditch near bridge, Carona to Fullers.	5.87	.82	4.80
Do.	.....do.....	"K" Bridge, Carona to Fullers.	35.92	1.53	55.15
June 21	.....do.....	"N," 2 miles below Rincon, left bank.	2.05	1.55	3.18
Do.	.....do.....	"M," river in narrows 2 miles below Rincon.	46.54	1.71	79.81
June 22	.....do.....	Division gate S. A. V. Irrigation Co. and Anaheim Union Co.	40.52	1.66	67.47
Do.	.....do.....	5 miles below division box A. U. W. Co.	19.01	1.82	34.74
Do.	.....do.....	S. A. V. Irrigation Co. ditch near bridge to Yorba.	19.47	1.49	28.99
June 30	.....do.....	Gage Canal, Palm avenue	(a)	.....	27.42
July 1	.....do.....	Jurupa Ditch.....	.....	.....	5.60
Sept. 8	.....do.....	River at Warm Springs.....	21.83	1.602	35.01
Do.	.....do.....	Santa Ana Canal	.....	.....	1.66
	.....do.....	Total at mouth of canyon	.....	.....	36.67
Do.	.....do.....	Bolen Tunnel.....	.....	.....	1.24
Do.	.....do.....	Green Spot pipe line.....	.....	.....	(b)
Do.	.....do.....	Head Highlands Canal.....	.....	.....	13.29
Do.	.....do.....	Alessandro, water in S. A. Canal.	.....	.....	1.66
Do.	.....do.....	Redlands Canal	.....	.....	15.40
Aug. 30	.....do.....	Total flow river, division box U. A. and S. A. V. Co.	28.33	1.86	52.89
Do.	.....do.....	Cement ditch S. A. V. I. Co....	16.54	1.49	24.62
Aug. 27	.....do.....	Jurupa Ditch.....	5.39	1.85	10.18
Do.	.....do.....	Total flow river 1¼ miles below Riverside Water Co., lowest canal division.	.53	.94	.50
Do.	.....do.....	Head lower canal, Riverside..	3.71	1.98	7.35
Aug. 28	.....do.....	Roubidoux Ditch, "C"	6.79	1.25	10.18
Do.	.....do.....	Ditch to Chinese garden.....	5.56	.88	4.87
Do.	.....do.....	Spring Brook.....	3.83	.37	1.27
Do.	.....do.....	River in narrows below Riverside.	27.16	1.44	39.05
Do.	.....do.....	River in Rincon Narrows	40.45	1.65	66.82
Sept. 22	.....do.....	Gage Canal, total flow	(a)	.....	26.24
Do.	.....do.....	Davis Ditch	.....	.....	.37
June 12	Mill Creek.....	McIntosh water at road crossing.	.14	2.00	.28
Do.	.....do.....	Crafton Canal, total flow of creek.	1.92	9.42	18.10
July 23	.....do.....	.....do.....	(a)	.....	11.82
Sept. 8	.....do.....	Crafton Canal, total flow of creek.	1.23	10.62	13.07
Do.	.....do.....	McIntosh water at road crossing.	.14	2.00	.28
June 24	Los Angeles River.	In creek below Macy street...	.....	.....	c.50
Do.	.....do.....	Diversion below Zanja No. 7..	4.96	.013	.64
Do.	.....do.....	Zanja No. 7.....	4.05	1.38	5.59
Aug. 10	.....do.....	New bridge.....	(a)	.....	1.28

a Weir. b Dry. c Approximate.

Measurements of low-water stage in California during June, July, August, September, and October, 1898, etc.—Continued.

Date.	Stream.	Locality.	Area of section.	Mean velocity.	Discharge.
			Sq. feet.		*Sec.-feet.*
Aug. 10	Los Angeles River.	San Fernando road crossing..	(a)	.....	4.84
Do.	.....do.....	North Cahuenga road.....	(a)	.....	9.74
Do.	.....do.....	Old bridge No. 4.....	(a)	.....	14.45
Do.	.....do.....	Tajunga Creek at junction....	(a)	.....	.87
Aug. 15	.....do.....	Bridge No. 2 at narrows.....	20.90	1.85	38.74
Do.	.....do.....	Main supply ditch	11.08	1.48	16.42
Do.	.....do.....	Total river at Crystal Springs	.....	.....	55.14
July 1	San Gabriel River.	Duarte water.....	.....	.....	3.59
Do.	.....do.....	Azusa water.....	.....	.....	11.78
June 21	.....do.....	Headworks in canyon.....	(a)	.....	13.21
July 3	.....do.....	Temple Ditch	3.19	2.84	9.06
Do.	.....do.....	Baldwins Ranch house road, first channel.	6.80	1.39	8.79
Do.	.....do.....	Original channel of river	6.61	.93	6.18
Do.	.....do.....	Camper's station No. 11.....	4.06	.83	3.36
Do.	.....do.....	Puente Ditch.....	.....	.....	2.44
Do.	.....do.....	Old Mission Bridge	13.94	2.14	29.79
Do.	.....do.....	Total flow at Puente Narrows	.....	.....	61.63
Do.	.....do.....	Whittier Ditch.....	.88	2.86	2.52
Aug. 16	.....do.....	Headworks in canyon.....	(a)	.....	5.16
Aug. 31	.....do.....	Flume Whittier Ditch	3.62	.50	1.80
Do.	.....do.....	Temple Ditch	2.67	2.57	6.88
Do.	.....do.....	Old channel	5.39	1.45	7.81
Do.	.....do.....	No. 10, No. 11	9.16	.67	6.17
Do.	.....do.....	Old Mission Bridge.....	13.61	2.05	27.91
Aug. 16	.....do.....	Total flow at Puente Narrows	.....	.....	52.60
Aug. 23	.....do.....	Headworks weir in canyon...	.....	.....	8.42
Do.	.....do.....	Mouth East Fork.....	4.50	1.58	7.11
Do.	.....do.....	Mouth West Fork.....	3.47	.77	2.67
Do.	.....do.....	Azusa flume, lower tunnel developed water.	.356	.146	.52
July 1	.....do.....	Monrovia Canyon.....	1.36	.98	1.33
June 18	Santa Clara River.	Camulos Ranch.....	9.57	2.15	25.74
Aug. 11	.....do.....	2 miles east Camulos	9.23	1.88	17.36
Aug. 9	.....do.....	Flume one-half mile above San Francisquito Creek.	9.00	1.20	10.83
July 10 to July 17	Kern River.....	South Fork, 700 feet above junction.	8.03	1.61	12.94
	.....do.....	South Fork, near old engineer camp.	27.60	.65	17.85
	.....do.....	South Fork, sec. 6, T. 22 S., R. 36 E., M. D. M.	11.82	.85	10.05
	.....do.....	South Fork, Monache Meadows.	5.11	1.04	5.31
	.....do.....	North Fork, near junction ...	.....	.....	380.50
Aug. 29	.....do.....	First point of measurement, Bakersfield.	72.53	1.585	115.02
July 2	.....do.....	Monrovia Canyon	1.36	.98	1.33
Do.	San Antonio River.	In canyon.....	(a)	.....	7.59
Do.	.....do.....	Ontario water, near division box.	.347	1.096	.38
Do.	.....do.....	Ontario water, below division box.	2.24	1.72	3.87
Do.	.....do.....	Pomona water at Pierces Camp.	1.97	1.70	3.36
Aug. 26	.....do.....	In canyon.....	(a)	.....	10.01
Aug. 11	Sespe River.....	Division point.....	2.66	.92	2.46
Do.	Piru Creek.....	French House	1.46	.53	.92
Do.	San Francisquito Creek.	.....	1.84	1.12	2.07
Do.	Little Tejunga River.	.....	.....	.....	.05
Aug. 26	Cucamonga River.	.....	.78	1.33	1.04
Sept. 16	Arroyo Seco	Total flow into Orange Grove avenue reservoir.	.318	1.88	.598
Do.	.....do.....	Flume pumped from Sheep Corral Springs.	2.32	.73	1.69
Do.	.....do.....	Marengo Improvement Co. reservoir.	.155	9.50	1.47
Do.	.....do.....	Reservoir No. 1 P. and L. V. L. and W. Co.	2.64	1.36	3.605
Do.	.....do.....	Tunnel junction Devils Gate, main supply.	2.70	1.02	2.75
Oct. 14	.....do.....	Reservoir No. 1.....	.....	.....	(b)
Sept. 7	Whitewater River.	Above Palm Valley Water Co. headworks.	4.14	2.26	9.35

a Weir. b Dry.

INDEX TO PAPERS NOS. 27 AND 28.

Page.

Alabama, hydrographic work in 45, 48, 54–58
Albany, Ga., hydrographic work at 47, 49–50
Alderson, W. Va., hydrographic work at. 59, 61, 65
Almon, Ga., hydrographic work at..... 31–32
Alston, S. C., hydrographic work at.. 28, 39, 44, 45
Amicalola River, measurements of..... 45
Amity Canal, measurements of 109, 114, 117
Androscoggin River, measurements of... 9, 14–16
Animas River, measurements of.. 132, 139, 142, 145
Antietam Creek, measurements of... 10, 19, 23, 24
Arboles, Colo., hydrographic work at..... 131, 138–139, 142. 145
Arizona, hydrographic work in 132–133, 140–143, 145
Arkansas River, measurements of..... 107–108, 109, 110–112, 113–114, 116, 117
Arkins, Colo., hydrographic work at.. 77, 83, 86, 89
Arnold, Sydney, aid by..... 8, 153, 168, 169
Arroyo Seco, measurements of 196
Asheville, N. C., hydrographic work at..... 59, 62, 65, 66
Augusta, Ga., hydrographic work at 28–31, 40–41, 44, 46
Austin, Tex., hydrographic work at 118–119, 122–124, 129, 130
Azusa Canal, measurements of..... 191
Babb, C. C., work of..... 29, 68, 74, 75, 132, 142, 153, 155, 156, 168, 169
Baker, J. S., work of..... 146, 153
Battle Creek, Idaho, hydrographic work at. 148, 149, 153, 154
Beach, C. W., work of..... 108, 109, 116
Bear Creek, Colorado, measurements of.. 77, 81, 86
Bear River, Utah, measurements of 146, 149, 150, 153, 154
Beaver River, measurement of..... 88
Big Thompson Creek, measurements of.... 77, 83, 86, 89
Bitterroot River, measurements of..... 156, 163, 168–169, 170
Black Fork, measurements of.... 131, 133, 142, 144
Black Warrior River, measurements of. 48. 56, 58
Blackfoot River, measurements of 155–156, 163, 168, 170
Blake, Utah, hydrographic work at .. 131, 134. 144
Blue River, measurements of..... 90, 94, 95, 96
Blueridge, Ga., hydrographic work at. 60, 64, 65, 66
Boise, Idaho, hydrographic work at..... 155, 161, 168, 169
Boise River, measurements of.... 155, 161, 168, 169
Bonner, Mont., hydrographic work at..... 155, 156, 163, 168, 170
Boulder, Colo., hydrographic work at. 77, 82, 86, 89
Boulder Creek, measurements of..... 77, 82, 86, 89
Bozeman, Mont., hydrographic work at.... 68, 70, 74, 75
Brazos River, measurements of .. 118, 121, 129, 130
Broad River, Georgia, measurements of.... 31, 43, 44, 46
Broad River, South Carolina, measurements of..... 27–28, 38–39, 44, 45
Brown, C. N., work of..... 60, 65
Brown, G. W., cited..... 29
Bruneau River, measurements of.... 155, 161, 169
Bryson, N. C., hydrographic work at. 59, 63, 65, 66
Buchanan, Va., hydrographic work at.. 10. 22, 24
Buffalo, Wyo., hydrographic work at. 69. 73–74, 76
Buttes, Ariz., hydrographic work at. 133, 140, 142
Caldwell, H. W., work of..... 23

Page.

Calhoun Falls, S. C., hydrographic work at. 28, 40, 44, 46
California, hydrographic work in..... 106, 177–196
Calowa River, measurements of..... 171, 175, 176
Camp Clarke, Nebr., hydrographic work at..... 76, 80, 86, 88
Campbell, A. Q., work of 191
Canton, Ga., hydrographic work at. 47–48, 51, 57, 58
Canyon, Colo., hydrographic work at..... 107, 110, 116, 117
Cape Fear River, measurements of... 26, 36, 44, 45
Carlton, Ga., hydrographic work at.. 31, 42, 44, 46
Carters, Ga., hydrographic work at. 45, 48, 52, 57, 58
Cary, Ga., hydrographic work at..... 31, 43, 44, 46
Catawba, N. C., hydrographic work at..... 27, 37, 44, 45
Catawba River, measurements of . 27, 37–38, 44, 45
Cedar River, measurements of..... 171, 172–173
Chattahoochee River, measurements of 45, 47, 50–51, 57, 58
Chattanooga, Tenn., hydrographic work at. 60, 64, 65, 66
Chinook, Mont., gaging station at..... 69
Clark, W. B., aid by..... 8
Clarksville, Va., hydrographic work at.. 25, 33, 44
Clear Creek, measurements of 69, 73–74, 76
Cogswell, F., work of..... 86
Cole, Burt, aid by 186, 190
Collinston, Utah, hydrographic work at..... 146, 150, 153, 154
Colorado, hydrographic work in..... 77–78, 81–84, 86, 89, 107–113, 116, 117, 120, 126, 129–132, 135–139, 142–145
Colorado River, measurements of 118–119, 122–124, 129, 130, 133, 141, 143
Colton, A. T., aid by..... 8. 132, 142
Columbus, Nebr., hydrographic work at. 78, 85, 87
Columbus, Ohio, hydrographic work at.... 60, 65
Conn, J. C., work of 44. 57, 65
Conversion tables 96–100
Coosa River, measurements of.... 48, 53–55, 57, 58
Coosawattee River, measurements of. 48, 52, 57, 58
Crowe, H. F., work of..... 191, 192
Dallas, Tex., hydrographic work at.. 118, 121, 129
Dan River, measurements of..... 25, 33, 44
Deep River, measurements of..... 26, 35, 44
Del Norte, Colo., hydrographic work at.... 120, 126, 129, 130
Delaware River, measurements of. 9, 16, 23. 24, 130
Denver, Colo., hydrographic work at. 77. 84, 86, 89
Deschutes River, measurements of... 159, 167, 169
District of Columbia, hydrographic work in..... 10, 22. 24
Dobson, Adna, aid by 8, 87, 95
Dolores, Colo., hydrographic work at..... 131, 138, 142, 144
Dolores River, measurements of.. 131, 138, 142, 144
Dougall, W. B., work of..... 146, 153
Duarte Canal, measurements of..... 191
Dublin, Ga., hydrographic work at... 31, 43, 44, 46
Dungeness River, measurements of.. 171, 174, 176
Durango, Colo., hydrographic work at..... 132, 139, 142, 145
El Paso, Tex., hydrographic work at..... 120, 128
Elk Creek, Nebraska, measurement of..... 88
Elk River, Colorado, measurement of 143
Elkhorn River, measurements of.... 78, 85, 87, 88
Elko, Nev., hydrographic work at..... 145–146, 147. 153, 154
Ellijay River, measurement of..... 45

Page.
Ellsworth, Kans., hydrographic work at .. 90, 93, 95, 96
Elrod, M. J., work of 168, 169
Elwha River, measurements of..... 171, 174, 176
Embudo, N. Mex., hydrographic work at .. 120, 127, 129, 130
Emery, Roe, aid by 8, 74–75
Emery, S. M., aid by 8
Etowah River, measurements of.. 47–48, 51, 57, 58
Fallcreek, Colo., hydrographic work at.... 131, 137, 142, 144
Farish, W. A., aid by 8, 143
Fayette, W. Va., hydrographic work at. 59, 62, 65
Fayetteville, N. C., hydrographic work at.. 26, 36, 44, 45
Fellows, A. L., aid by..... 8, 86, 107, 116, 142, 143
Field, J. E., work of 86
Flint River, measurements of..... 47, 49–50, 57, 58
Florence Canal, measurements of 142
Florida, hydrographic work in..... 45
Flynn, B. H., work of..... 60, 66, 67, 68
Forks, Wash., hydrographic work at. 171, 175, 178
Fort Crawford, Colo., hydrographic work at. 131, 136, 142, 144
Fort Niobrara, Nebr., gaging station at..... 69
Fortier, Samuel, aid by..... 8, 146, 153
Frederick, Md., hydrographic work at..... 10, 21, 24, 25
Fremont, Ohio, hydrographic work at..... 67, 68
French Broad River, measurements of..... 59, 62, 65, 66
Frenchman River, measurement of..... 88
Friendsville, Md., hydrographic work at..... 59, 61, 65
Gaffney, S. C., hydrographic work at. 27–28, 38, 44
Gallatin River, measurements of..... 68, 70, 74, 75
Geneva, Utah, hydrographic work at 146, 154
Georgia, hydrographic work in..... 28–32, 40–53, 57, 58, 60, 64–66
Gering, Nebr., hydrographic work at. 76, 80, 86, 88
Gibbon, Oreg., hydrographic work at..... 159, 167, 169, 170
Gila River, measurements of..... 133, 140, 142
Glasgow, Va., hydrographic work at.... 10, 22, 24
Golconda, Nev., hydrographic work at.... 146, 148, 153, 154
Granada, Colo., hydrographic work at... 109, 114
Grand Junction, Colo., hydrographic work at..... 131, 135, 136, 142, 144
Grand River, measurements of... 131, 135, 142, 144
Grandview, Idaho, hydrographic work at... 155, 161, 169
Granite, Colo., hydrographic work at 107, 110, 116, 117
Great Gunpowder River, measurements of, 24
Green River, measurements of.131, 134, 142, 143, 144
Greenbrier River, measurements of..... 59, 61, 65
Greenriver, Wyo., hydrographic work at... 131, 134, 142, 144
Guadalupe River, measurements of .. 119, 124, 129
Gunnison River, measurements of.131, 136, 142, 144
Hall, B. M., aid by..... 8, 29, 30, 31, 44, 45, 57, 65, 66
Hall, Max, work of..... 44, 45, 57, 65
Hall, O. P., work of..... 45, 57
Hall, Warren, work of..... 44, 45
Harrisburg, Pa., hydrographic work at.... 9, 17, 23, 24
Harroun, P. E., aid by..... 8, 129
Havre, Mont., hydrographic work at. 68, 72, 75, 76
Haw River, measurements of..... 25–26, 35, 44
Hawley, R. W., work of..... 116
Herndon, Cal., hydrographic work at... 179–180, 183, 185, 186, 193
High Bridge, Tex., hydrographic work at. 119–120, 126
Hiwassee River, measurements of..... 45, 60, 64, 65, 66
Holmes, J. A., aid by..... 8
Holston River, measurement of 66
Hood, O. P., work of..... 95
Hood River, measurements of..... 159, 168, 169
Hooper, Wash., hydrographic work at..... 155 162, 168, 170
Humboldt River, measurements of..... 145–146, 147–149, 153, 154
Humphreys, D. C., aid by..... 8, 24, 44, 59, 65, 66
Hutchinson, Kans., hydrographic work at.. 109, 114, 116, 117

Page.
Idaho, hydrographic work in..... 146, 149, 153–155, 159–162, 168–170
Iola, Kans., hydrographic work at..... 110, 115, 116, 117
James River, measurements of..... 10, 22, 24
Jefferson River, measurements of.... 68, 71, 74–75
Jellys Ferry, Cal., hydrographic work at... 171, 183, 185, 186, 193
Johnson, Charles, quoted..... 158
Johnston, C. T., aid by..... 8, 86, 142
Judson, N. C., hydrographic work at. 59, 63, 65, 66
Junction City, Kans., hydrographic work at..... 90, 92, 95, 96
Kansas, hydrographic work in 90–96, 109, 110, 114–117
Kansas River, measurements of... 90–91, 94, 95, 96
Kaweah River, measurements of..... 192
Kennebec River, measurements of..... 9, 11–14
Kern River, measurements of..... 181, 185, 196
Kings River, measurements of..... 180, 181, 184, 185, 186, 193
Kingsburg, Cal., hydrographic work at.. 180–181, 184, 185
Kiona, Wash., hydrographic work at..... 159, 165, 169, 170
Knights Ferry, Cal., hydrographic work at 185, 193
La Platte River, measurement of..... 143
Lagrange, Cal., hydrographic work at... 178–179, 183, 185, 186, 193
Lake Chelan, measurements of .. 157–158, 163–164
Lake McDonald, measurements of..... 118, 119
Lakeside, Wash., hydrographic work at.. 157–158, 163, 164
Lambertville, N. J., hydrographic work at. 9, 16, 23, 24
Laramie River, measurements of.. 76, 78–79, 86, 88
Las Animas, Colo., hydrographic work near 109, 113, 116
Laurel, Md., hydrographic work at .. 10, 18, 23, 24
Laurel Hill Creek, measurement of 66
Lawrence, Kans., hydrographic work at.. 90–91, 94, 95, 96
Lemstrom, Fred, work of 177, 185
Lewis, Tex., hydrographic work at. 118, 121, 129
Liberty, Kans., hydrographic work at..... 109, 115, 116, 117
Ling, C. W., work of..... 75
Lippincott, J. B., aid by..... 8, 106, 180, 185, 186, 188, 190–191, 192
Little Snake River, measurement of..... 143
Little Tejunga River, measurements of.. 192, 196
Little Tennessee River, measurements of.. 59, 63, 66
Little Wood River, measurements of..... 155, 160, 168, 169
Littlerock Creek, measurements of 186–187, 189, 190, 191
Livingston, Mont., hydrographic work at.. 69, 73, 76
Logan, Mont., hydrographic work at. 68, 70, 74, 75
Logan, Utah, hydrographic work at..... 146, 150, 153, 154
Logan River, measurements of... 146, 150, 153, 154
Long Pine River, measurement of..... 88
Long Swamp Creek, measurement of 45
Lord, H. S., work of 169
Los Angeles River, measurements of. 192, 195–196
Los Pinos River, measurements of 143
Loup River, measurements of..... 78, 84, 87
Lovell, Wyo., hydrographic work at 69, 73, 76
Lozier, Tex., hydrographic work near. 119–120, 128
Lyons, Colo., hydrographic work at.. 77, 83, 86, 89
Lytle Creek, measurements of 192, 194
McDonald, Wash., hydrographic work at . 171, 174, 176
McDowell, Ariz., hydrographic work at 133, 140–141, 143, 145
Macon, Ga., hydrographic work at ... 32, 43, 44, 46
Madison, S. C., hydrographic work at. 28, 40, 44, 46
Madison River, measurements of..... 68, 71, 74, 75
Maine, hydrographic work in..... 9, 11–16
Malad River, measurements of... 155, 160, 168, 169
Mancos, Colo., hydrographic work at 131, 137, 142, 144
Mancos River, measurements of.. 131, 137, 142, 144
Manhattan, Kans, hydrographic work at.... 90, 94, 95, 96

Page.
Mansanola, Colo., hydrographic work at... 108, 112, 116
Margueretta Canal, measurements of. 119, 125, 130
Marshall, Colo., hydrographic work at..... 77, 82, 86, 89
Maryland, hydrographic work in 10, 17–19, 21, 23–25, 59, 61, 65
Masons Ranch, Nev., hydrographic work at. 146, 148–149, 153, 154
Matthes, G. H., work of 142, 143
Maumee River, measurements of 66, 67, 68
Maybell, Colo., hydrographic work near.... 143
Mexico, Ohio, hydrographic work at.... 66–67, 68
Middle Creek, measurements of..... 68, 70, 74, 75
Middle Loup River, measurements of..... 88
Milk River, measurements of..... 68–69, 72, 75, 76
Mill Creek, measurements of 189, 192, 195
Mills, F. J., aid by 146, 153, 155, 168
Millville, W. Va., hydrographic work at ... 10, 20, 23, 24, 25
Milstead, Ala., hydrographic work at..... 48, 56, 57, 58
Minnechadusa River, measurements of 88
Missoula, Mont., hydrographic work at.. 156–157, 163, 168, 169, 170
Missoula River, measurements of..... 156–157, 163, 169, 170
Missouri River, measurements of.... 68, 72, 75, 76
Mixer, C. A., aid by 9
Modesto, Cal., hydrographic work at..... 179
Molina, Ga., hydrographic work at... 47, 49, 57, 58
Moncure, N. C., hydrographic work at..... 25–26, 35, 44
Monocacy River, measurements of... 10, 21, 24, 25
Montana, hydrographic work in 68–76, 155–157, 163, 168–170
Montgomery, Idaho, hydrographic work at. 155, 160, 168, 169
Moro, Oreg., hydrographic work at... 159, 167, 169
Morrison, Colo., hydrographic work at.. 77, 81, 86
Murphy, E. C., aid by 8, 95, 116
Murphy, N. C., hydrographic work at..... 60, 64, 65, 66
Myers, E. W., aid by 8, 44, 45, 65
Naches River, measurements of..... 158, 164, 170
Neal, N. C., hydrographic work at ... 25, 33, 44, 45
Nebraska, hydrographic work in..... 69, 76, 78, 86, 81, 85–88, 95
Neosho River, measurements of.. 110, 115, 116, 117
Nepesta, Colo., hydrographic work at..... 108, 112, 116, 117
Neuse River, measurements of..... 25, 34, 44
Nevada, hydrographic work in... 145–149, 153, 154
New Braunfels, Tex., hydrographic work at..... 119, 124, 129, 130
New Jersey, hydrographic work in... 9, 16, 23, 24
New Mexico, hydrographic work in. 120, 127–130
New River, measurements of..... 59, 61, 62, 65
Newell, F. H., letters of transmittal by.... 6, 106
Newman, George, aid by..... 188
Niles, Kans., hydrographic work at.. 90, 92, 95, 96
Niobrara River, measurements of..... 69, 88
Noble, T. A., aid by 171
Norfolk, Nebr., hydrographic work at.. 78, 85, 87
North Branch of Potomac River, measurements of..... 24
North Carolina, hydrographic work in 25–27, 33–37, 44, 45, 59, 62–66
North of James River, measurements of. 10, 22, 24
North Platte, Nebr., hydrographic work at. 76, 81, 86, 88
North Platte River, measurements of..... 76, 78–81, 86, 88
North River, Virginia, measurements of. 10, 19, 25
North Yakima, Wash., hydrographic work at..... 158, 164, 170
Oakdale, Cal., hydrographic work at 177–178, 182, 185, 186, 193
Oakdale, Ga., hydrographic work at and near..... 45, 47, 50, 57, 58
Ocmulgee River, measurements of ... 32, 43, 44, 46
Oconee River, measurements of..... 31, 43, 44, 46
Octoraro Creek, measurements of 10, 17, 23, 24
Ogden, Utah, hydrographic work at..... 146, 151, 153, 154
Ogden River, measurements of.. 146, 151, 153, 154
Ohio hydrographic work in..... 60, 65–68
Oleutangy River, measurements of..... 60, 65
Page.
Olmstead, F. H., work of..... 185, 191, 192
Oostanaula River, measurements of.. 48, 52, 57, 58
Orchard, Colo., hydrographic work at..... 77–78, 84, 86, 89
Oreana, Nev., hydrographic work at..... 146, 148, 153, 154
Oregon, hydrographic work in..... 159, 167–169
Orin Junction, Wyo., hydrographic work at. 76, 79, 86, 88
Palmdale, Cal., hydrographic work at ... 186–187, 189, 190, 191
Palouse River, measurements of.. 155, 162, 168, 170
Parkinson, H. F., aid by..... 187
Patapsco River, measurements of.... 10, 18, 23, 24
Patuxent River, measurements of.... 10, 18, 23, 24
Paul, E. G., work of..... 23–24, 59, 65, 66
Pecos, Tex., hydrographic work near. 119, 125, 130
Pecos River, measurements of. 119–120, 125–126, 130
Pedee River, measurements of..... 26, 37, 44
Peko, Nev., hydrographic work at..... 143, 147, 153, 154
Pennsylvania, hydrographic work in..... 9, 17, 23, 24, 66
Platte River, measurements of..... 78, 85, 87, 88
Piedra River, measurements of.. 131, 139, 142, 145
Pocatello, Idaho, hydrographic work at.... 155, 159, 168, 169
Point of Rocks, Md., hydrographic work at. 10, 21, 25
Port Republic, Va., hydrographic work at. 10, 19–20, 25
Portneuf River, measurements of. 155, 159, 168, 169
Potomac River, measurements of.... 10, 21, 24, 25
Pressey, H. A., work of..... 60, 66, 67, 68
Preston, P. J., work of..... 108, 116
Proctor Creek, measurement of..... 45
Provo, Utah, hydrographic work at..... 146, 152, 153, 154
Provo River, measurements of... 146, 152, 153, 154
Pueblo, Colo., hydrographic work at..... 108, 111, 116, 117
Purgatory River, measurements of..... 108, 113, 116, 117
Queen Creek, measurements of..... 132–133
Quillayute, Wash., hydrographic work at.. 171, 175, 176
Radford, Va., hydrographic work at 59, 61, 65
Ranger, Wyo., hydrographic work at..... 131, 133, 144
Red Mountain, Cal., hydrographic work at..... 180, 184, 185, 186, 193
Redbluff, Mont., hydrographic work at.... 68, 71, 74, 75
Redbluff, N. Mex., hydrographic work at.. 130
Redlands Canal, measurement of..... 192
Republican River, measurements of..... 89–90, 91–92, 95, 96
Resaca, Ga., hydrographic work at.. 48, 52, 57, 58
Rhead, J. L., work of..... 146, 153
Rialto Canal, measurement of..... 192
Rio Grande, measurements of..... 120, 126–130
Rio Grande, N. Mex., hydrographic work at..... 120, 127, 129, 130
Riverside, Ala., hydrographic work near.. 48, 54, 57, 58
Riverside, Cal., hydrographic work near.. 192, 194, 195
Roanoke, Va., hydrographic work at. 25, 32, 44, 66
Roanoke River, measurements of.. 25, 32, 33, 44, 45
Rock Creek, measurements of..... 10, 22, 24
Rockhill, S. C., hydrographic work at..... 27, 38, 44, 45
Rocky Ford, Colo., hydrographic work at..... 108, 112, 116, 117
Rome, Ga., hydrographic work at ... 48, 53, 57, 58
Ross, C. P., work of..... 86
Rowlandsville, Md., hydrographic work at..... 10, 17, 23, 24
Rumford Falls, Me., hydrographic work at..... 9, 14–16
Russell, W. G., aid by..... 8, 95, 116
Sacramento River, measurements of 177, 182, 185, 186, 193
St. Vrain Creek, measurements of....77, 83, 86, 89
Saleeville, Mont., hydrographic work at... 68, 69, 74, 75
Salida, Colo., hydrographic work at 107, 110, 116, 117

Page.

Salina, Kans., hydrographic work at. 90, 93, 95, 96
Saline River, measurements of..... 90, 93, 95, 96
Salisbury, N. C., hydrographic work at.. 25, 36, 44
Salt River, measurements of..... 133, 140, 143, 145
Saluda River, measurements of..... 28, 39, 44, 46
San Antonio River, California, measurements of..... 196
San Antonio River, Texas, measurements of..... 130
San Felipe River, measurement of..... 130
San Francisquito Creek, measurement of.. 196
San Gabriel River, measurements of.... 187–188, 189, 190–191, 192, 196
San Joaquin River, measurements of.... 179–180, 183, 185, 186, 193
San Juan River, measurements of..... 131, 138, 142, 143, 145
San Marcial, N. Mex., hydrographic work at..... 120, 128, 129, 130
San Marcos River, measurement of..... 130
San Miguel River, measurements of..... 131, 137, 142, 144
Sandusky River, measurements of..... 66–67, 68
Santa Ana Canal, measurements of 191, 192
Santa Ana River, measurements of..... 188–189, 190, 191, 192, 194–195
Santa Clara River, measurements of 196
Sappington, Mont., hydrographic work at.. 68, 71, 74–75
Savannah River, measurements of 28–31, 40–42, 44, 46
Scioto River, measurements of 60, 65
Seattle, Wash., hydrographic work near ... 171, 172–173
Seguin, Wash., hydrographic work at 171, 174, 176
Selma, N. C., hydrographic work at 25, 34, 44
Sespe River, measurements of..... 196
Sharpsburg, Md., hydrographic work at.... 10, 19, 23, 24
Shenandoah River, measurements of 10, 20, 23, 24, 25
Shirley, F. S., aid by 8, 153, 155, 168
Shoshone River, measurements of..... 69, 73, 76
Slater, Colo., hydrographic work at 143
Smith, F. D., work of..... 168
Smith, G. E., aid by 8, 87–88, 95
Smoky Hill River, measurements of.. 90, 93, 95, 96
Snake River, Colorado, measurement of 143
Snake River, Idaho, measurements of 155, 160, 168, 169
Soda Springs, Idaho, hydrographic work at.. 146, 149, 153, 154
Solduck River, measurements of..... 171, 175, 176
Solomon River, measurements of..... 90, 92, 95, 96
South Boulder Creek, measurements of 77, 82, 86, 89
South Carolina, hydrographic work in..... 27–28, 38–40, 44–46
South Platte River, measurements of..... 77–78, 84, 86, 89
South River, measurements of 10, 20, 25
Spokane, Wash., hydrographic work at 159, 166, 169, 170
Spokane River, measurements of. 159, 166, 169, 170
Stanislaus River, measurements of..... 177–178, 182, 185, 186, 193
Staunton River, measurements of..... 25, 33, 44
Stinking Water River, measurement of 88
Stout, O. V. P., aid by..... 8, 87, 95
Superior, Nebr., hydrographic work at. 89–90, 91, 95
Susquehanna River, measurements of. 9, 17, 23, 24
Tallapoosa River, measurements of... 48, 56, 57, 58
Tar River, measurements of..... 25, 34, 44
Tarboro, N. C., hydrographic work at... 25, 34, 44
Taylor, L. H., aid by..... 8, 145, 153
Taylor, T. U., aid by..... 8, 118, 119, 129, 130
Tennessee, hydrographic work in.... 45, 60, 64–66
Tennessee River, measurements of... 60, 64, 65, 66
Texas, hydrographic work in.... 118–126, 128–130
Thomas, K. T., work of..... 44
Toccoa River, measurements of..... 60, 64, 65, 66

Page.

Toponis, Idaho, hydrographic work at..... 155, 160, 168, 169
Townsend, Mont., hydrographic work at... 68, 72, 75, 76
Trinidad, Colo., hydrographic work at..... 108, 113, 116, 117
Trinity River, measurements of.. 118, 121, 129, 130
Trull, Colo., hydrographic work at..... 143
Tuckaseegee River, measurements of... 59, 63, 65
Tucker, Oreg., hydrographic work at.. 159, 168, 169
Tugalo River, measurements of..... 28, 40, 44, 46
Tulare Lake, measurement of..... 192
Tule River, measurement of..... 194
Tuolumne River, measurements of..... 178–179, 183, 185, 186, 193
Tuscaloosa, Ala., hydrographic work at.. 48, 56, 58
Uinta, Utah, hydrographic work at..... 146, 151, 153, 154
Umatilla River, measurements of..... 159, 167, 169, 170
Uncompahgre River, measurements of..... 131, 136, 142, 144
Union Gap, Washington, hydrographic work at..... 159, 165, 169, 170
Utah, hydrographic work in..... 131, 134, 143, 144, 146, 150–154
Utah Lake, measurements of..... 146, 152
Uva, Wyo., hydrographic work at... 76, 78, 86, 88
Verde River, measurements of..... 133, 141, 143
Verdigris River, measurements of..... 109, 115, 116, 117
Vickerys Creek, measurement of..... 45
Virginia, hydrographic work in 10, 19–20, 22, 24, 25, 32, 33, 44, 59, 61, 65, 66
Vogleson, J. A., work of..... 191
Waco, Tex., hydrographic work at... 118, 121, 129
Wallawalla River, measurements of..... 159, 166
Ware, W. J., aid by..... 8, 171
Warmsprings, Cal., hydrographic work at. 188–191
Washington, hydrographic work in 155, 157–159, 162–166, 168–176
Washington, D. C., hydrographic work at. 10, 22, 24
Waterloo, S. C., hydrographic work at..... 28, 39, 44, 46
Waterville, Me., hydrographic work at... 9, 11–14
Waterville, Ohio, hydrographic work at. 66, 67, 68
Weber River, measurements of.. 146, 151, 153, 154
Weiser, Idaho, hydrographic work at..... 155, 162, 168, 170
Weiser River, measurements of.. 155, 162, 168, 170
West Gallatin River, measurements of..... 68, 69, 74, 75
West Point, Ga., hydrographic work at ... 47, 51, 57, 58
West Virginia, hydrographic work in 10, 20, 23–25, 59, 61, 62, 65
Wetumpka, Ala., hydrographic work near . 48, 55
White River, Colorado, measurement of.... 143
White River, Nebraska, measurements of.. 88
Whitewater River, measurement of..... 196
Whitman, Wash., hydrographic work at. 159, 166
Wiley, A. J., aid by 155
Williams River, measurement of..... 143
Willis, R. H., work of..... 86
Wills Creek, measurements of..... 24
Woods Landing, Wyo., hydrographic work at..... 76, 78, 86, 88
Woodstock, Md., hydrographic work at.... 10, 18, 23, 24
Wyoming, hydrographic work in..... 69, 73–74, 76, 78, 79, 86, 88, 131, 133, 134, 140, 142, 143
Yadkin River, measurements of..... 26, 36–37, 44
Yakima River, measurements of. 159, 165, 169, 170
Yampa River, measurements of..... 143
Yeates, W. S., aid by 8
Yellow River, measurements of..... 31–32
Yellowstone River, measurements of.... 69, 73, 76
Youghiogheny River, measurements of.... 59, 61, 65, 66
Yuba River, measurement of..... 193
Yuma, Aris., hydrographic work of..... 133, 141

DEPARTMENT OF THE INTERIOR

WATER-SUPPLY

AND

IRRIGATION PAPERS

OF THE

UNITED STATES GEOLOGICAL SURVEY

No. 29

WASHINGTON
GOVERNMENT PRINTING OFFICE
1899

UNITED STATES GEOLOGICAL SURVEY
CHARLES D. WALCOTT, DIRECTOR

WELLS AND WINDMILLS

IN

NEBRASKA

BY

ERWIN HINCKLEY BARBOUR

WASHINGTON
GOVERNMENT PRINTING OFFICE
1899

CONTENTS.

	Page.
Letter of transmittal	11
Importance of water resources	13
Action of water underground	14
Sheet water	17
Artesian water	18
Conservation of soil moisture	24
Pollution of water	26
Surface and seepage water	27
Fluctuations of water level	28
Methods of raising water	28
Homemade windmills	31
Cost	34
Classification	34
Distribution	35
Jumbo windmills	35
Baby jumbo windmills	37
Jumbo windmills of intermediate size	38
Screw jumbo windmills	41
Construction of jumbo windmills	42
Pumps	44
Merry-go-round windmills	44
Open-faced or turbine windmills	47
Battle-ax windmills	47
Holland windmills	54
Towerless turbines	56
Stationary turbines	56
Vaneless automatic turbines	59
Giant turbines	60
Reconstruction of windmills	64
Shopmade turbines	65
Original uses for shopmade windmills	66
Other forms of water lifters	67
Transmission and storage of windmill power	69
Precipitation in Nebraska	71
Surface water available for irrigation	73
Supply for towns and cities	73
Salt water	75
Blowing wells	78
Index	83

ILLUSTRATIONS.

		Page.
PLATE I.	*A*, Riverview Park artesian well, near Omaha; *B*, Artesian well in Holt County	18
II.	*A*, Artesian well at Beaver Crossing; *B*, Well of T. M. Ferguson at Beaver Crossing	24
III.	*A*, Platte River, near Gering; *B*, Dam at Milford	28
IV.	*A*, Windmill and tower; *B*, Experimental windmill at farm of University of Nebraska	30
V.	*A*, Baby jumbo windmill on Goodrich farm, near Bethany, Nebraska; *B*, Baby jumbo built by J. L. Brown, Kearney, Nebraska	36
VI.	Mounted jumbo windmill on Goodrich farm, near Bethany, Nebraska	36
VII.	*A*, Medium-sized jumbo windmill in garden of M. J. Olson, Cozad, Nebraska; *B*, Large jumbo windmill at Cushman Park Gardens, Lancaster County, Nebraska	38
VIII.	*A*, Jumbo windmill in Travis gardens, near Lincoln, Nebraska; *B*, Screw jumbo windmill	38
IX.	*A*, Method of attaching arms of jumbo windmill to axis; *B*, Another method of attaching arms of jumbo windmill to axis	40
X.	*A*, Method of construction of six-fan jumbo windmill cross-braced by twisted wire; *B*, Method of construction of eight-fan jumbo windmill	40
XI.	*A*, Method of construction of gangs of jumbo windmills of a diameter of from 12 to 14 or more feet and of indefinite length; *B*, Method of construction of screw jumbo windmills with canvas sails and arms braced with twisted wire	42
XII.	*A*, Gang of jumbo windmills erected above corncribs or sheds; Jumbo windmill with wind guard or cut-off	42
XIII.	Small mounted merry-go-round windmill near Lincoln, Nebraska	44
XIV.	*A*, Merry-go-round windmill built by S. S. Videtto, Lincoln, Nebraska; *B*, Suggested form for eight-fan merry-go-round windmill	46
XV.	*A*, Battle-ax windmill on farm of Matthew Wilson, near Overton, Nebraska; *B*, Battle-ax windmill on farm of Fred Woulf, near Grand Island, Nebraska	48
XVI.	*A*, Six-fan battle-ax windmill of John Harders, near Grand Island, Nebraska; *B*, Eight-fan battle-ax windmill of Diedtrich Huennecke, near Grand Island, Nebraska	50
XVII.	*A*, Giant battle-ax windmills on farm of J. S. Peckham, near Gothenburg, Nebraska; *B*, Two-fan battle-ax windmill built by Elmer Jasperson, Ashland, Nebraska	52

Page.

PLATE XVIII. *A*, Dutch windmill of August Prinz, near Chalco, Nebraska; *B*, Six-fan Dutch windmill of Henry Bormann, near Portal, Nebraska 54

XIX. *A*, Four-fan stationary turbine mill of Friederich Ernstmeyer, near Grand Island, Nebraska; *B*, Six-fan stationary turbine of Fred Mathiesen, near Grand Island, Nebraska 56

XX. *A*, Giant turbine built by J. M. Warner, near Overton, Nebraska; *B*, Four-fan geared turbine built by Henry Boersen, near Grand Island, Nebraska 58

XXI. *A*, Reconstructed windmill of E. M. Searles, jr., at Ogallala, Nebraska; *B*, Irrigating pond and reconstructed windmill on farm of Elmer Jasperson, near Ashland, Nebraska 60

XXII. *A*, Railroad water tank and windmill; *B*, Elevated tanks filled by windmill for town supply, used at Fairmont, Fillmore County, Nebraska 62

XXIII. Ponds of the Moulton Ice Company, Lincoln, Nebraska, supplied with water by two turbine windmills 64

XXIV. Windmill and water elevator on Blue River, near Milford, Nebraska 66

XXV. *A*, Thirty-foot current water wheel on branch of Hat Creek, Sioux County, Nebraska; *B*, thirty-five foot current water wheel near Hot Springs, South Dakota 68

XXVI. Waterworks at Kearney, Nebraska 74

XXVII. Burlington Beach, near Lincoln, Nebraska 76

FIG. 1. Course of water percolating from surface of soil down to saturated area 14

2. Inclined water table on eroded rocky floor 15

3. Open windlass and well curb 29

4. Partly inclosed windlass and well curb 30

5. Jumbo windmill of M. J. Olson, Cozad, Nebraska 40

6. Jumbo windmills and reservoirs in the market gardens of Travis Bros., Lincoln, Nebraska 40

7. Break resulting from improper method of fastening jumbo windmill arms on the axis 42

8. Hooded merry-go-round built by William Winn, Berwin, Nebraska, showing semicircular hood on rollers guided by large rudder 44

9. Plan of hooded merry-go-round windmill built by William Winn 45

10. Plan of large merry-go-round windmill of E. E. Blackman 46

11. Details of construction of battle-ax windmills 48

12. Working parts of the four-fan battle-ax windmill on the farm of Matthew Wilson, Overton, Nebraska 49

13. Method of construction of the battle-ax mill of Fred Woulf, near Grand Island, Nebraska 50

14. Working parts of the eight-fan battle-ax windmill of Diedtrich Huennecke, near Grand Island, Nebraska, with one fan in position 51

15. Battle-ax windmill driving crosscut saw, built by A. G. Tingley, Verdon, Nebraska 54

16. Stationary turbine designed and built by Janak Bros., Sarpy Mills, Nebraska 58

17. Sketch of homemade steel turbine of W. F. Baldwin, Ainsworth, Nebraska 59

Page.

FIG. 18. Method of regulating the fans of the homemade steel turbine of W. F. Baldwin 60
19. Method of construction of four-fan turbine mill of Henry Boersen, near Grand Island, Nebraska 61
20. Homemade turbine mill of Lewis Jardee, of Newport, Nebraska 62
21. Side view and details of revolving parts of homemade turbine windmill of W. F. McComb, Grand Island, Nebraska 63
22. Two-foot tympanum water wheel operated by 12-foot aermotor 67
23. Transmission of power of windmill by oscillating wires 70
24. Monthly precipitation in Nebraska 71
25. Plan of waterworks at Kearney, Nebraska 74

LETTER OF TRANSMITTAL.

DEPARTMENT OF THE INTERIOR,
UNITED STATES GEOLOGICAL SURVEY,
DIVISION OF HYDROGRAPHY,
Washington, February 15, 1899.

SIR: I have the honor to transmit herewith a manuscript entitled "Wells and Windmills in Nebraska," prepared by Erwin Hinckley Barbour, professor of geology in the University of Nebraska and acting State geologist. The data for this manuscript were obtained by Professor Barbour incidental to his studies of the geology of the State, and have been rounded out by special work carried on under his direction. The original manuscript as prepared consisted of two parts—the first upon wells, and the second upon homemade windmills—but owing to delays in printing the first part, it has been considered advisable to combine the two papers into one and thus secure earlier publication. The manuscript as thus combined is offered as one of the water-supply and irrigation papers.

In the earlier numbers of this series considerable space has been given to the subject of windmills and discussions of the results obtained by experiments. These facts have been presented in the hope of stimulating the development of more economical and efficient methods of raising water for irrigation. In the present paper another phase of the matter is presented, and it is shown that by the use of material at hand a thrifty and ingenious farmer can produce results worthy of imitation. It is not to be supposed that homemade devices will be as efficient as those made for competition in the open market, but in the country, far from centers of population, it is not always practicable for the farmer to obtain such machinery. Lack of ready money and difficulty of transportation may prevent his obtaining the best windmill or pump. Under these conditions it is infinitely better for him to use the means at hand rather than go without. It has been shown by Professor Barbour that where one man in a community invents and builds a useful device of this kind others are quick to imitate, so that one homemade windmill or pump is copied on neighboring farms for miles around.

It is pointed out in this paper that the homemade windmill is not necessarily a contrivance incident to poverty or hardship. Many of the mills of this kind have been made by men who might afford to

buy shopmade mills, but who, having sufficient ingenuity and possessing the necessary materials, have preferred to combine these to produce effective machinery. They have merely exercised in this direction the thrift whose existence is shown by countless other tokens about their farms. The homemade windmill must not, therefore, be considered an indication of poverty, but rather the reverse, since it is usually accompanied by progress in all lines.

The subject matter of this paper is related to water conservation in the small way. Throughout the Great Plains region the supply of water is so scanty and so widely disseminated that as a rule it will be impracticable to provide great storage reservoirs or other works of considerable magnitude. On the other hand, for the utilization of the resources there must be innumerable attempts to employ the small amount of water almost everywhere available; and this can be done most economically through the use of the ever-present force of the wind. Thus windmills throughout at least one-fourth of the United States must ever be inseparably connected with the utilization of wells and with the development of the country.

Very respectfully,

F. H. NEWELL,
Hydrographer in Charge.

Hon. CHARLES D. WALCOTT,
Director United States Geological Survey.

WELLS AND WINDMILLS IN NEBRASKA.[1]

By ERWIN HINCKLEY BARBOUR.

IMPORTANCE OF WATER RESOURCES.

In Nebraska, as in other portions of the Great Plains region, the principal source of wealth lies in the soil. The fertility of this section is marvelous and agricultural possibilities are such that subsistence may be obtained for a population of several millions; yet this domain is for the most part sparsely populated, the progress of settlement has been checked, and the tilled areas are increasing in extent but slowly. This apparent cessation of progress during 1894, 1895, and 1896, especially in the western half of the State, is due mainly to one cause, the insufficiency of rainfall.

Except the soil and its products, the natural resources of Nebraska are few. The consolidated rocks are deeply buried beneath clays, sands, and gravels; there are few, if any, minerals of commercial value, no beds of coal nor veins of ore, no fields of gas nor oil, but water, owing to its comparative scarcity and its importance in agricultural economy, rises to the rank of a mineral resource of the greatest importance. The development and employment of all of the supply flowing on the surface or percolating underground necessitates a study as thorough as that given by other States to coal, iron, or precious metals.

This paper has been prepared as a preliminary study of the water problem in Nebraska. In it the attempt is made to review briefly the general subject of the water supply, to bring together the more obvious facts, and to state these so that they may be understood by the farmer or citizen not skilled in technical or scientific practice. The facts on which the paper is based were gained in part by personal observation, and were supplemented by correspondence carried on by printed schedules and letters. The discussion is general in character, treating of the behavior of water underground, and particularly of the methods of bringing it to the surface for domestic use and for use in agriculture. Reference is also made to the surface waters of the

[1] Notes and data respecting wells have been brought down to the spring of 1897; those respecting windmills to the spring of 1899.

State and the amount of rainfall, some facts are given concerning the salt or saline waters and their utilization, and the peculiar blowing or breathing wells are briefly described.

ACTION OF WATER UNDERGROUND.

Air, which is the vehicle for moisture, can carry a greater load when it is dry, warm, and in motion. If the air is cooled, it can no longer carry its burden, which is dropped from the clouds as rain. Follow the course of the raindrops, or the circulating water, as it is aptly called, from the moment of impact with the surface and it will be seen that (1) a portion runs off, washing eastern soils badly, but washing western less; (2) a portion soaks in, since the soil is sandy, as it does not in clay soil; (3) a portion is evaporated, the average annual evaporation in Nebraska amounting to 4 or 5 feet; and (4) a portion, insignificant in amount, is taken up by plants and animals.

The portion that soaks into the soil sinks by its own weight deeper and deeper through the capillary or hair-like passageways and is lost

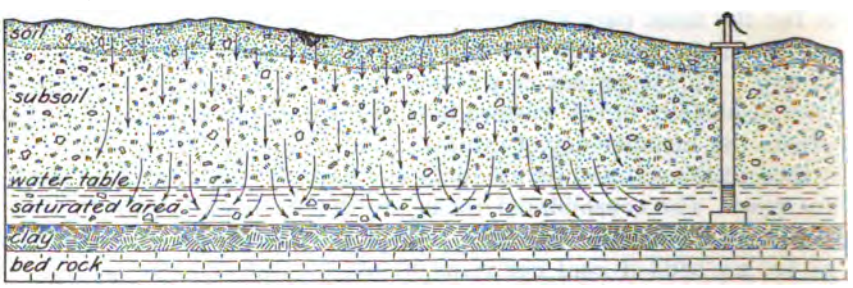


FIG. 1.—Course of water percolating from surface of soil down to saturated area.

to sight. It is universal experience that the soft, permeable surface material may change below to harder or even impermeable layers. Then it is that the water in its downward course is turned aside to flow laterally in all directions. Friction, however, greatly retards its movement. Constant additions are received as the rains continue, so that the creeping waters pile up, as it were, and gradually rise higher and higher; that is, the water table or water plane is rising.

As the process continues the creeping layer must rise to or near the surface of the soil, and thus the ground becomes water-logged—that is, soaked or saturated with water. (See fig. 1.) At such times springs are flowing, the ponds and streams fed by them are full, wells are inexhaustible, and vegetation is luxuriant and continues so during dry weather or even moderate drought. Let the season of drought continue and the creeping waters eventually steal away, and the saturated area is reduced to nothing; that is, the water table is settling. At such times ponds, springs, wells, and streams may fail—the more superficial first, the deeper last. Fresh showers cause them slowly to rise again, or perhaps they may rise without precipitation by acces-

sions of water at some more remote spot, or from the seepage of some river swollen by floods at its source. Or, in still a third case, they may rise in an apparently mysterious manner without the intervention of showers or flood, simply because of hydrostatic connection with some other region which is flooded.

The water table, then, is subject to rise and fall because of water received at home or from abroad. It is not an entirely stable body preserving a constant level, but is subject to seasonal variations and variations incident to cycles of dry and wet years. The water table is not necessarily level, but is usually so, for instead of following the rocky floor the water table may run parallel with the surface. The floor, as well as the surface, is apt to be undulatory and the water plane or table higher or lower, according to the material passed through, to the escape of the water, and to other modifying causes. (See fig. 2.)

The ground water or free water, as it may be called, is evidently in circulation and subject to fluctuation. The wells of the region likewise vary, although this is scarcely worthy of mention in the case of Nebraska, from the fact that nearly all of the counties report an unlim-

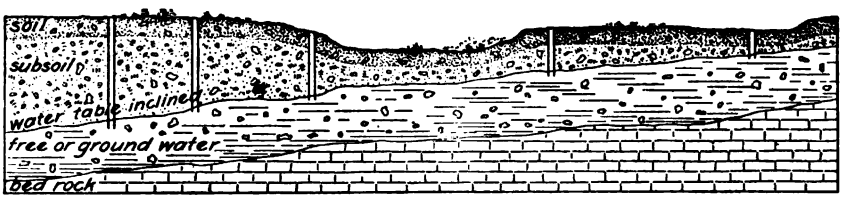


FIG. 2.—Inclined water table on eroded rocky floor.

ited water supply, with inexhaustible wells. When the water table rises to within half a yard of the surface, vegetation suffers or is drowned out. On the other hand, when the water settles too far, plants may suffer equally from lack of water to carry soluble plant food to their roots and rootlets. When, however, the water table stands at a mean level between these two extremes, the fields of the State, with an annual rainfall of but 23.3 to 25 inches, produce crops and withstand droughts in a manner astonishing to the citizens of regions possessing double the annual precipitation. At first it seemed incredible that such magnificent yields could come from so insignificant a rainfall. Nevertheless the fact stands. There are two apparent reasons for this. The rainfall in many eastern regions amounts to 35 or 40 inches, but one-half is lost by running off and carrying with it valuable soil fertility, the other half soaking into the ground, while in Nebraska the water lost as run-off is only about one-tenth. Hence, here a far greater proportion of storm water is stored for future use. This is largely due to the sandy nature of the soil. Even some of the so-called clay soils, though looking and acting like clay, are in fact exceedingly fine sand.

From the mechanical analyses of soils and subsoils made thus far it is shown that Nebraska soils are peculiarly rich in sands and poor in clays. The amount of sand—including in this term coarse, medium, and fine sand and silt—runs as high as 97 to 98 per cent. The lowest percentage thus far is about 66 per cent, while the average is probably about 78 per cent, based on the analyses made by Prof. Milton Whitney, of the Department of Agriculture. In a word, there is a preponderance of sand in Nebraska soils, which renders them at once light and capable of readily imbibing a larger proportion of rainfall than is possible in eastern States. This is a very significant fact.

The more one cultivates the virgin prairie, which when hard packed sheds water like a roof, the greater will be the amount of storm water caught and stored in the soil and the less the run-off and evaporation. Increased cultivation tends toward the conservation of soil moisture, and this in turn reacts, making it possible to catch more moisture, since soil already damp imbibes more rainfall than a dry soil. Thus as settlement goes on the amount of precipitation absorbed increases and the amount lost becomes even less. This statement must not be confounded with the popular but erroneous belief that the annual precipitation is increasing.

But when the spring rains cease and a season of settled weather or possibly drought sets in, and the surface soil dries, a force of great interest and of profoundest importance begins to act. This force is capillarity, by virtue of which water is drawn up through the minute, hair-like passageways of the soil and subsoil, rising automatically as much as 6 or 7 feet. This, then, is a second way by which water is held in the soil, and its far-reaching importance is instantly apparent when one considers that the very passageways up which this water is drawn are those down which rootlets grow. Soil moisture laden with soluble plant food is thus carried up to the rootlets or feeders of growing vegetation. Crops and grasses are nourished by capillary water and saved by it uninjured in time of drought, even during seasons of long-protracted dryness (if not accompanied by hot winds), such as could not but blight crops and grasses elsewhere. However, it is not to be forgotten that this force works equally well both ways, thereby carrying moisture up or down, according as the surface soil or the deep subsoil is the drier. This only emphasizes the importance of utilizing all available rainfall in saturating the deeper soil as completely as possible, in order that the full energy of capillary attraction may be expended in drawing soil moisture to the rootlets.

Thus far two means have been considered by which water is held by the soil—first, as ground water, sinking by gravity, and, second, as capillary water. There is another means so subtle and concealed as to merit little more than passing notice—hygroscopic water, which is inherent in many minerals, rocks, soils, and substances, and may be obtained by long-continued roasting.

SHEET WATER.

There is in common parlance a rather indefinite and puzzling use of the terms, first, second, and third water, and sheet water. By first water is meant the first surface water that seeps into the well; a supply often weak and readily exhausted. By second or sheet water, as it is commonly called, is understood the deeper ground water, which is unlimited in amount, since it is contained in porous material that delivers water rapidly. Third water, as the term is popularly used, is doubtless the same second water struck at a lower level, after passing through a local layer of fine material of slow delivery.

Sheet water is a greatly abused term, about which has gathered false impressions not easily dispelled. It carries with it wherever used the idea of subterranean water, flowing at an exaggerated rate under the ground. It is perfectly true that ground water flows and that it has certain channels, naturally decided by the coarseness or fineness of the material, but one hears repeatedly of well diggers striking subterranean currents of sheet water flowing at the apparently incredible rate of 4 or 5 miles an hour, a faster rate than that of the Platte itself. This fallacious statement is made repeatedly in all sincerity and good faith. A very popular conception of this torrential sheet water is that it is the angry and pent-up floods of subterranean caves, which are seeking outlets to the sea. This erroneous conception is worse than fallacious; it is entirely misleading.

There is no such current in the sheet water, and there are no such extensive caves and underground lakes, and can not be in the sandy soil of Nebraska. Caves are formed in limestones, not in sands, for naturally the sand would cave in and fill any great underground passageways as fast as formed. This misconception comes about naturally enough in some cases, and is cherished with a faith not to be shaken. The well digger, who, while bailing or pumping out the water on one side of the well, sees water flowing in from the other, can tell without hesitation in which direction the water flows, for he "has seen it himself;" but let him set his pump on the opposite side of the well and the current will set in from the other direction.

Of course there is a current whose rate is regulated by the coarseness or the fineness of the material through which it flows, but this same current is inconceivably slow. Coarse material with rapid delivery of water may have a current as slow as a fraction of a foot a day, or as rapid as several feet a day, while in fine-grained, compact soil the rate is reduced to little or nothing. A better understanding of the power of delivery of various materials would correct many of these errors.

If an old pail or keg, having holes in the bottom, is filled with clean, coarse pebbles, and a stream of water poured in, the rate of delivery is practically as rapid as the rate at which the water is poured. Its rate is so rapid that the water flows down through the gravel in a

column, scarcely wetting the other pebbles. With the sand, however, the water spreads out or is diffused through much or all of the mass, and is delivered slowly at the bottom. In the silt, which is impalpably fine sand, the rate is still slower and the whole mass is saturated with water. In clay—the fineness of which is extreme—there is no delivery at all in experiment and practically none in nature. Mix together gravel, sand, silt, and clay, about as they occur in nature, and the rate becomes about the same as that of the finest material—that is, water is delivered with extreme slowness.

This set of experiments tends to show the rate at which water can flow through soil or rock of various degrees of porosity, and disproves the statement that the velocity of underground currents is in any way comparable with that of surface streams.

ARTESIAN WATER.

Ground water is almost universal and is the source of the supply of common wells. In addition to this there is the extraordinary subterranean water which supplies artesian wells. In the common house well the water seeps in and stands quietly at a certain level. In the artesian well it comes in under pressure. This is the only essential difference between the two. The artesian wells in Artois, France, from which the name "artesian" is derived, were the first dug and observed. These were spouting wells from deep sources; hence the term artesian presupposes in the public mind a spouting well from deep-seated sources.

This early conception, however, is not the true one. Many artesian wells are shallow, not over 60 to 80 feet in depth, but yet are true artesian wells. Many throw fine streams from a few inches to several feet high, and are unquestionably artesian wells; but a short distance away at a higher level the same water will rise in the well under the same pressure and is likewise artesian, even though the head is not sufficient to force it above the surface. The one is an active, positive, flowing artesian well; the other a negative, passive, or standing artesian well.

In Johnson and Seward counties the shallow artesian wells are beautifully represented. They occur in valleys where the surface has been washed away and lowered, thus enabling the pressure or "head" to force the water above the surface 10 to 12 feet. On this level flowing wells are everywhere to be found, which are already put to many economic uses, and farms which are models of their kind draw their water for irrigation from this source with no cost. These are positive or flowing artesian wells. On farms a few feet higher precisely the same water is struck. It rises to the surface, but can not flow over it.

It is universal experience that rocks, some soft and porous, some dense, are found in the State arranged in horizontal beds. The denser

A RIVERVIEW PARK ARTESIAN WELL, NEAR OMAHA, NEBRASKA.

Depth, 1,060 feet; capacity, 114,427 gallons a day; 6-inch pipe; water but slightly saline; temperature, 62°; cost, $1,000. This well supplies annually to the park system of Omaha a volume of water which, at the lowest wholesale city water rate, would cost $5,000 a year, and illustrates the use of artesian water for the beautifying of parks. In addition to the fountain and stream a small lake is supplied by the well.

B. ARTESIAN WELL IN HOLT COUNTY, 18 MILES SOUTH OF O'NEILL, ON THE FREMONT, ELKHORN AND MISSOURI VALLEY RAILROAD.

layer will constitute the impervious jacket around the more porous layers. The layers which are deeply buried here, and but inappreciably tipped, may come to the surface elsewhere and form a catchment basin, perhaps at a point far distant, as is the case presumably with the deeper wells found along the northern and northeastern boundary of the State.

The artesian wells, as far as reported, fall into four rather natural groups, as follows: The deep wells of the Carboniferous, such as those at Beatrice, Lincoln, and Omaha, varying from 556 to 2,463 feet; the artesian wells of the Dakota sandstone, 300 to 400 feet deep, being a continuation into Nebraska of the South Dakota artesian basin; the shallow wells in glacial sands and clays, such as those at Cook, Beaver Crossing, and elsewhere; and other shallow wells not in the drift, such as those in Holt and Rock counties. (See Pl. I, *B*.)

There are local artesian basins in the State which are more easily compassed than the deep wells. There are small basins of 10 to 15 square miles each in the valleys of streams, depressed noticeably below the general level of the surrounding hills. Within this circumscribed area, wherever the impervious roofing or encasement of clay is pierced—the depth varying from 40 to 100 or more feet—there comes a strong and constant flow. Such wells are too shallow to come from strata which draw their water supply from a distance, so that it is necessary to look for some other explanation.

It is at once apparent that this artesian supply is drawn from beds of alternating gravel, sand, and clay, deposited by glacial action during the ice age, and that it is rather limited and local, though none the less important, as has been sufficiently demonstrated by its multifarious uses at Beaver Crossing and adjoining localities. Farther downstream the wells, instead of growing stronger, grow weaker. This is due to some leak or escape of the water through the impervious clay roof, which results in a reduction of head or pressure in all adjacent wells.

The alternating and confused arrangement of these beds comes about naturally, because of the way in which the glacier and iceberg deposited coarse, medium, and fine material together into heterogeneous piles—clay here, sand there; sand, gravel, and pebbles elsewhere. The porous gravelly layer, incased above and below by layers of clay, is not necessarily of uniform texture, but, instead, there occur among the coarser material patches or islands of finer material. Hence as the well is in this patch or that, its head or pressure will be accelerated, retarded, or stopped outright, according to the rate of delivery of water in coarse, fine, or clayey material. One farm at Cook, Johnson County, in the midst of flowing wells, has failed, and always must fail, to furnish artesian water, and there is apparently nothing anomalous in the case. The farm is over what is called a "clay island." All the wells dug on this farm penetrate clay only, and, of course, one can not hope to strike artesian water there.

List of artesian wells.

Name of well.	County.	Town.	Depth.	Remarks.	Year.
			Feet.		
Lincoln test well	Lancaster	Lincoln	2,468	6-inch pipe; throws water 5 feet above surface; salt water.	
Artesian well, Government square.	do	do	1,080	Bed rock at 95 feet; salt water 160 feet; first flow 560 feet.	
Sulpho-saline bath	do	do	556	Strong flow; salt water; 100,000 gallons per day.	
David Swaney	do	5 miles west of Lincoln.	240	Slight flow	
Willow Springs distillery or Iler's well.	Douglas	Omaha	1,700 to 1,800	First flow at 700 feet; second flow at 1,700 feet; pressure 87 pounds per square inch; used for boiler.	
Pickard's or "Well No. 1."	do	6 miles west of Omaha.	1,383	Heavy flow at 517 feet, 676 feet, and 894 feet; strongest flow at 1,080 feet; pressure 150 pounds.	
Courtland Beach or Cut-off Lake well.	do	3 miles northeast of Omaha.a	998	6-inch pipe; throws water 40 feet; 86,000 gallons per day.	1894
Riverview Park well.	do	2 miles south of Omaha.	1,064	4-inch pipe; 114,427 gallons per day; slightly saline. Feeds a lake of 2 to 4 acres. Temperature, 62°.	
Omaha Packing Company.	do	South Omaha	1,800	Negative artesian, rising 70 feet to surface; strongly mineral. Temperature, 62°. Too warm for condensers.	
Elkhorn	do	Elkhorn	65	Soft water; cost, $45	1887
Lloyd Lunn	Adams	Near Hastings	114	6-inch pipe; cost, $31	1888
William Kearville	Boyd	T. 34, R. 8	760	Cost, $2,000; used for irrigation; 100 gallons per minute.	1895
Cal. Moffett	do	Sec. 2, T. 34, R. 12		Used for irrigation; 15 barrels per minute.	
G. L. Emmons	do	Sec. 18, T. 33, R. 8		Used for irrigation; 2,000 barrels per day; cost, $1,000.	1895
L. M. Short	Brown	5 miles from Ainsworth, in Sec. 9, T. 29, R. 22.	32	8-inch pipe; 40 gallons per minute; soft water; cost, $6. (?)	1895
C. W. Conkling	Burt	Tekamah	108	Three wells, 3, 4, and 8 inch, for city water supply.	
Craig	do	Craig	126	Flowing water at 120 feet. CO_2 blown off for several days.	

a Really in Iowa, because of meanderings of Missouri River.

List of artesian wells—Continued.

Name of well.	County.	Town.	Depth.	Remarks.	Year.
			Feet.		
A. E. Johnson	Cass	Weeping Water, sec. 16, T. 10, R. 12.	8	Ceased to flow, 1894	
Numerous wells	Cedar		a 263	Average cost, $146; hard water.	
C. A. Johnson	Cherry	Woodlake, sec. 21, T. 31, R. 28.	100	Slight pressure; cost, $50; hard water; 100 gallons per hour; railroad well.	1892
A. Strong	do	Sec. 21, T. 31, R. 28.	17	Soft water	1892
B. A. Jones	Cheyenne	Near Sidney, sec. 20, T. 13, R. 45.	94	Negative artesian; cost, $75; by aid of pump. *b*	1886
J. E. Melcher	Cuming	Wisner	97	Used for irrigation; 2 barrels per minute; hard water; cost, $97.	1895
P. G. Cooper	Dawes	Crawford	86	12-inch stream, easily lowered; hard water; cost, $50.	
H. E. Grant	do	Sec. 25, T. 32, R. 52.	82	600 gallons per day; soft water; cost, $100.	1888
James Moseller	do	Sec. 12, T. 32, R. 52.	18.5	2-inch pipe; soft water; good pressure until filled with sand.	1891
F. P. Ryan	Dixon	Ponca	407	60 gallons per minute	1885
Do	do	do	265	do	1894
Geo. Mattison	do	7 miles from Ponca.	484	Flowed three weeks and stopped; stands 6 feet below the surface; cost, $50.	1888
Fred Heine	Dodge	3 miles north of Hooper.	304	40 gallons per minute; hard water.	1892
Beatrice	Gage	Beatrice	1,260	Very salt; dug for city supply and abandoned; intermittent flow	
J. J. Connoly	Garfield	Erina	110	Flows 6 feet above surface; soft water; cost, $11.	1894
P. A. McDonald	do	Sec. 15, T. 24, R. 14.	140	Soft water; constant flow; cost, $30.	1894
Benjamin Jones	do	Sec. 22, T. 24, R. 14.	175	3 feet above surface; soft water; 5 gallons per minute; cost, $37.	1894
A. J. Plumer	Grant	Hyannis, sec. 23, T. 25, R. 28.	450	4 gallons per minute; soft water; cost, $225.	1895
Numerous wells	Holt		55 to 120	Soft water; average cost, $10 to $30.	
Edward De Merritt	Hooker	Mullen			
Herman Kracker	Johnson	4½ miles from Elk Creek, sec. 34, T. 4, R. 12.	146	Cost, $200	1894
J. J. Wilson (3 wells)	do	4 miles from Cook, sec. 1, T. 6, R. 10.	80	3 wells cost $90; fine soft water. *c*	1893

a Average depth.
b Used to water 2,000 sheep and to irrigate garden.
c One well from 4-inch nozzle keeps a 1-acre pond, 4 feet deep, full all the time.

List of artesian wells—Continued.

Name of well.	County.	Town.	Depth.	Remarks.	Year.
			Feet.		
J. W. Holden	Johnson	4 miles from Cook, sec. 6, T. 6, R. 11.		Cost, $20	1895
Many wells	Knox		504 to 770	Cost from $225 to $3,000; majority hard water.	
John Coker	Lincoln	9 miles from Sutherland, sec. 6, T. 14, R. 34.	22	Soft water; doubtful if this is really artesian.	
Lew Williams	Logan	Gandy	81	Cost $80; soft and only artesian well in the county; pipe often choked up; good pressure.	1891
Hy. Rainer	Loup	Taylor	80	Hard water	
R. E. Haskell	McPherson	Lena	42	Cost $25; soft water; 4 gallons per minute.	1895
White Water ranch	do	Sec. 32, T. 20, R. 35.	30	Cost $15; 15 gallons per hour; soft water.	1888
August Tannehill	Madison	6 miles from Norfolk, sec. 27, T. 25, R. 1.	125	Cost $90; 30 gallons per minute; medium hard.	1892
E. D. Gool	Nance	8 miles from Fullerton, sec. 14, T. 17, R. 8.	28	Cost $100; says water rises through 3-inch gas pipe for 24 feet.	1892
Geo. Young	Nemaha	2½ miles from Brock.	52	Cost $32; soft water	1892
J. G. Burriss	Otoe	¼ mile from Cook.	75	Cost $20; one barrel per minute; used for irrigation; about 25 such wells in vicinity.	1891
Chas. Dorneau	do	4 miles from Unadilla, sec. 28, T. 9, R. 10.	282	Salt water; 30 gallons per hour; cost $282.	1889
Capt. S. V. Moore	Pawnee	6 miles from Pawnee, sec. 8, T. 2, R. 11.	10	Cost $15; said to flow in wet seasons; has sufficient water for 200 head of stock.	1888
Will Patterson	do	3½ miles from Burchard, sec. 36, T. 2, R. 9.	85	Cost $35; unlimited amount of hard water; slow flow, about 20 barrels per day.	1891
J. F. Wenzl	do	Steinauer, sec. 33, T. 3, R. 11.	11	Cost $40; flows in wet seasons; soft water.	1892
John McKenzie	Perkins	5 miles from Madrid, sec. 19, T. 10, R. 36.	150	Used for irrigation; cost $150; soft water.	1894
Many wells	Platte		12 to 100	Majority shallow; cost from $50 to $100; one salt and others soft water.	
John Beckstrom	Polk	Stromsburg	104	Cost $75; unlimited amount of hard water.	1887

List of artesian wells—Continued

Name of well.	County.	Town.	Depth.	Remarks.	Year.
			Feet.		
Frank Nichols	Redwillow	McCook	405	Cost $200; oily water and weak flow, but flow has increased; experimental well.	1895
Many wells	Rock		95 to 143	Most costing from $30 to $40; all soft water.	
Dr. Geo. L. Miller	Sarpy	7 miles from Omaha, sec. 2, T. 14, R. 12.	1,430	Cost $5,000; pressure 15 pounds to square inch; soft water; fine artesian; supplies a 30-acre lake for ice and fish.	1891
Dr. Jos. Miller	Scotts Bluff	Gering	330	Cost $200; at first had a flow of 1,000 gallons per day, but filled up with sand and a pump is now used; soft water.	1894
Many wells	Seward		13 to 100	Used for irrigation; some hard and some soft water, ranging in cost from $18 to $65.	
Dr. S. Person	Stanton	8 miles from Pilger, sec. 6, T. 2, R. 3.	96	Used for irrigation; cost $77; hard water; declining flow, about 4 barrels per minute.	1895
R. C. Schwann	Valley	7 miles from Ord	70	Cost $52; soft water; 15 gallons per hour.	1893
William Fetch	Washington	Herman	76	Cost $75; soft water; good flow.	1897
William Rutledge	do	do	38	Cost $25; hard water; free flow.	1894
Solomon Sheets	do	do	37	Cost $25; hard water; 3 gallons per minute.	1894
Many wells	Wheeler		8 to 124	Cost from $8 to $75; all soft water.	
A. B. Codding	York	York		Unfinished; cost $300; flowed 5½ hours, then 9 hours, and stopped; drill is fast in sand rock 600 feet deep. Water to be used in mill pond.	
Eugene Wright (two wells).	do	do	240, 590	Cost $200; power wanted for flour mill, but flow at 500 feet too weak.	1895
Harry Hill	Otoe	Palmyra	280	Salt water; 15 barrels per day.	

These local artesian wells are already turned to admirable account in supplying ponds for fish culture, fountains for school yards and parks, and water for domestic use and for irrigation. (See Pl. II, *A* and *B*.) The last-named use is destined to become of considerable economic

importance. Some farmers have already from eight to ten 5-inch wells per farm with which to irrigate over 100 acres each. The number who have tapped the subterranean reservoir and allowed the imprisoned water to escape and to flow away aimlessly and uselessly far exceeds those who have put it to intelligent use. There is enough artesian water wasted thus to irrigate whole farms. What renders this matter all the more deplorable is the obstinacy of many people in insisting that the supply can not be exhausted. This view is wholly fallacious, and if persisted in may result in damaging or destroying altogether an important resource. Every well dug must diminish the head or pressure that much, whether the amount is perceptible or not. Unrestricted abuse of these water privileges can but result disastrously here as elsewhere. All this water should be most conscientiously used and conserved.

In several localities, noticeably in Rock County, near Kirkwood, there are strong springs which boil up with such force that if the water be confined by placing several joints of old stovepipe in the throat of the spring the pressure is sufficient to force the water several feet above the surface. Springs of this kind are numerous, especially in this vicinity. Since the water rises under pressure, the name "artesian spring" is applicable. Similar springs in Johnson County are called "mound" springs, because the water in the center appears to boil up and is higher than that of the edge. This boiling occasionally gives them the name "kettle" springs. Such springs near Sterling are 30 feet across, and the overflow is reported as 3 feet wide and 2 feet deep.

CONSERVATION OF SOIL MOISTURE.

The importance of the conservation of moisture has not yet had the general recognition which the subject merits. But each year brings unmistakable advance in this matter, as is shown by the construction of new reservoirs and dams across streams and draws, and by new methods of cultivation. These are on the increase, and were it not for the difficulties in the way of making water-tight reservoirs in sandy soil and the large amount lost by evaporation (averaging 4½ feet for the State), greater progress might be reported. The matter of conservation of soil moisture by superior cultivation, being a less obvious factor, is lost sight of by many, and yet by this means there have been, to the author's knowledge, some marked examples of success, standing in strong contrast to the failure of others. By pulverizing to extreme fineness a coarse soil, the absorption of water may be increased a thousandfold. Compress or "firm" the soil, and the attraction of capillary water is increased to that extent. Mulch the surface into fine, loose particles, and the capillarity which draws the moisture up to the plant rootlets is broken at that point, and a

A. ARTESIAN WELL AT BEAVER CROSSING, SEWARD COUNTY, NEBRASKA.

B. WELL ON FARM OF T. M. FERGUSON AT BEAVER CROSSING, NEBRASKA.

Depth to artesian water 80 to 90 feet. Height of pipe, 13 feet; diameter, 6 inches. Mr. Ferguson irrigates 112 acres from nine such wells, which cost $900.

blanket is formed for the retardation of evaporation and retention of moisture in the soil. By careful and intelligent farming, wide areas now abandoned, or held by indifferent, roving classes, will prove to have ample moisture for agriculture.

The results of close and conscientious farming are astonishing. One aged English couple living near Lincoln were forced to undertake farming in a small way for subsistence. The land was poor and the season was bad. All the neighboring tenants fled, and earned nothing during the entire summer. The aged couple farmed all the more closely, conserving the soil moisture in every way known to them. Starting on nothing, and struggling through the most trying season recorded in the State, at the end of the harvest they deposited in bank $100 above their expenses, which they afterwards spent judiciously in purchasing stock and necessary machinery for another year. These are small earnings, but, nevertheless, the difference between their methods of farming and that of their nomadic neighbors is infinite. It is such farming as this that makes the agricultural reputation of a great State.

During a recent trying summer the agent of one of the railroad companies in Nebraska escorted several parties of Eastern capitalists across the State. Contrary to the advice of those who thought the course injudicious, the railroad company took the tourists through the least promising as well as the most promising parts of Nebraska. In the heart and center of a deserted region in the arid belt, where the cornfields on the right were withered and abandoned, they repeatedly came upon farms on the left with magnificent fields and the appearance of prosperity. They found, on inquiry, that the nomadic neighbors were in their "prairie schooners," seeking easier jobs elsewhere, while the colonists left behind were farming with extreme care and were prospering. On the one farm the finest crops were grown; across the road none at all. The difference was due solely to the farmers, the one farming carefully and conscientiously, the other slothfully. When arid lands respond in most unpropitious times to careful and intelligent treatment, what may not be expected of the best? Confidence in the future of agriculture in semiarid and arid Nebraska was impressed and fixed in the mind of each tourist who saw this admirable and striking example of the results of intelligent farming. Taking advantage of the lessons taught by superior cultivation, the Burlington and Missouri River Railroad Company has initiated a most commendable series of agricultural experiments in the semiarid and arid nonirrigated portions of Nebraska and Kansas. Here a practical test will be made of the actual utility of soil-culture methods for the conservation of moisture. Experiment stations have been established at Holdrege, Alma, Oxford, McCook, Curtis, Brokenbow, Grant, and Hastings, in Nebraska, and at Oberlin, Wheeler, St. Francis, and Bird City, in Kansas.

The method to be pursued is substantially that introduced at Putney, South Dakota, by Mr. H. W. Campbell as early as 1885, a method promising to be even more important than irrigation because of its wider applicability. This process consists essentially of deep plowing, subsequent firming of the soil to increase capillarity, and light surface cultivation to break capillarity and check evaporation, and to this end special machinery has been designed. The method is often known as "dust-blanket farming," the idea being to cut the surface into a soil mulch or powdery condition in order to prevent loss of moisture.

Farmers along the Republican River as far west as Harlan County who have tried this method find that a diversity of crops is possible, and that while the number of acres cultivated is reduced about one-half, the yield is increased several fold. For instance, potatoes, which yielded an average of 212 bushels under this treatment, gave but 25 bushels per acre to neighbors who avoided this system of close farming on the ground that it was expensive and onerous.

During the last five years various means for catching and holding surface water have increased enormously, and now attention is directed to the results consequent upon the better conservation of soil moisture, all of which will aid in the reclamation of important tracts of remarkably productive land now idle and unoccupied. There are table-lands 200 to 300 feet above water where no amount of conservation of moisture on the surface or in the soil can avail; but, on the other hand, there are countless regions to be benefited thereby. Such table-lands, therefore, where grazing is notably good, should be turned over to stock raisers, and the lowlands to agriculturists. Each class would prove of benefit to the other. Community life could be formed in the valleys and the uplands left for grazing.

It is universally conceded that cattle raising is profitable, and that the small herder can make steady gains by watching his cattle more closely instead of turning them loose upon the range as formerly. It is an easy way to turn stock upon the common range, where no care is required winter or summer except at the time of the annual "round up." But by that method the chances for loss are greater. Its day is past in Nebraska, and it is now time for many small cattle raisers to occupy the land once grazed over by the herds of great companies. The grazing lands should be turned to better account, the conditions of the valley lands should be better understood, and many important tracts now deserted should be reclaimed. This will come about by the storage of storm waters, by irrigation, and by the conservation of soil moisture.

POLLUTION OF WATER.

The water for domestic supply is well purified. In the river current the water is exposed to the air, and thus purification by the process of oxidation goes on. The ground water is likewise purified.

But in its descent through the air, in its passage down the streams, or through the soil and rocks, water, which is the universal solvent, takes up certain acids and gases, and dissolves certain minerals, particularly lime (making hard water), iron (making chalybeate water), potash or soda (making alkali water), or salt (making saline water).

These are wholly inorganic ingredients and for the most part harmless. But there are other ingredients not to be detected by the sense of smell, sight, or taste, which come from organic decay. Water in closely settled regions is subject to dangerous pollution. It then becomes a vehicle for germs and contagious disease, and is not fit even for beasts. Wells should be so located and guarded that barnyard wash can not drain into them nor soak through the soil into them. The water filters through many feet of soil, and is pure and wholesome if proper precautions are observed. One may feel great confidence in the purity and healthfulness of water drawn from a well which passes through clay before striking water-bearing gravels.

The writer can not refrain from citing one specific case of well-water pollution. The occurrence of fever in three families in Omaha pointed unmistakably to the dairyman who supplied them with milk. On visiting the dairyman the city physician found three in his family suffering from the same fever. The seat of trouble seemed to be the well, which was so injudiciously located as to receive surface wash directly, and indirectly the offal from the house and barn, rendering the water at once nauseating and dangerous.

The cities of the State should zealously guard against the possible contamination of their water. Good water for city use is so easily obtained from groups or gangs of wells at reasonable depths that no community seems justified in drawing its supply from surface streams, which are subject to progressive deterioration as population increases.

SURFACE AND SEEPAGE WATER.

The marshes, ponds, lakes, and cut-off lakes are relatively few, and need no further mention at present. The rivers, however, are of growing economic importance, and the time seems near when they will be diverted from their channels into irrigating ditches. On this point many persist in cherishing the error that rivers can not be drained, maintaining that as rapidly as water is drawn off as much more rushes in to supply the loss.

The Platte River flows east across the entire State, and is presumably of greater importance than the Missouri River. Though becoming entirely dry in certain seasons, the Platte nevertheless supplies important areas with water for irrigation during the growing season. More important than this is the underflow water of the Platte. It is a singular and highly interesting river. Overloaded and taxed beyond its power, it can not carry its burden of sand out of the State. Accordingly its energy is spent in shifting its sand bars from side

to side and in forming a lace work of channels through its broad bed; but beyond this, it is receiving constant additions of fresh sand. Accordingly it has built up its bed with sand 50 to 200 feet or more. Through this alluvial material there is an underflow of broad extent on each side of the Platte throughout the State, which spreads out and constitutes in part the important underflow, or even some of the sheet water of the State. After the surface water of the Platte has been diverted for irrigation the underflow in its gravels can be drawn upon without limit if mechanical difficulties can be overcome. (See Pl. III, *A*.)

FLUCTUATIONS OF WATER LEVEL.

The years 1892, 1893, 1894, and 1895 were years of exceptional drought. The whole water table was lowered, and springs, ponds, streams, and many wells failed. During the winter of 1895 there was virtually no rain or snow. That is to say, there was no precipitation by which to account for an unexpected rise of water (apparently real) which began early in the winter, and reached a point in February and March which aroused general comment. Many, for the past three years, had knots tied in well ropes whereby the well buckets might be lowered each time into the shallow water without roiling it. It was soon noticed that the wells were filling unexpectedly, because the ropes were wet some 10 to 12 feet above the usual point. Water began to flow in channels hitherto entirely dry. The dry beds of ponds began to fill. Excavations for railroad embankments became lakelets. Springs which three years previously had supplied fish ponds, but had become dry, began to flow again; and damp spots began to appear in some farms. So many cases were reported in person or by letter that the author took pains to send out several thousand inquiries over the State. Two-thirds of those who answered had noticed an unexpected rise of water; one-third had not. The evidence is almost conclusive that this is real, and is a matter of annual occurrence.

One explanation is that the decreased evaporation and the increased cohesion of water in winter allows more ground water to accumulate. The majority reported the rise as occurring in February. Stockmen in the most arid portions of Nebraska depend implicitly upon this rise of water, which they assert is of annual occurrence, and independent of precipitation. This matter seems as worthy of critical study as any problem connected with our ground water.

METHODS OF RAISING WATER.

Peculiar and characteristic systems of hoisting water are found in vogue in widely separated counties. Some methods are very primitive and crude, while others show thought and ingenuity. It is very evident that the first simple windlass or pump put up in a community becomes the model after which others of precisely the same type are

A. VIEW DOWN NORTH PLATTE RIVER FROM THE WYOMING-NEBRASKA LINE

B. DAM ON THE BLUE RIVER AT MILFORD, SEWARD COUNTY, NEBRASKA.

patterned. Sometimes windlasses and pumps of communities, and even of towns, are built as if from one model, heedless of faulty design and poor construction. Two forms are illustrated below. (See figs. 3 and 4.) Occasionally one sees water drawn hand over hand by bucket and rope, but a much more common form, which is virtually the same with the direction of motion changed, is the rope and pulley. Were it not that this method is laborious and slow, men might draw water for stock and women for domestic use for years. As it is, these are soon replaced by windlasses having a mechanical advantage. In the construction of these there is an occasional display of thought, and one man will make one stick of timber answer where three, four, or five sticks would have been used by another. Others are elaborated until the cost exceeds that of a good pump. Many prefer the open well and windlass to pumps, on supposed sanitary grounds, assuming that the iron pipe is unhealthful.

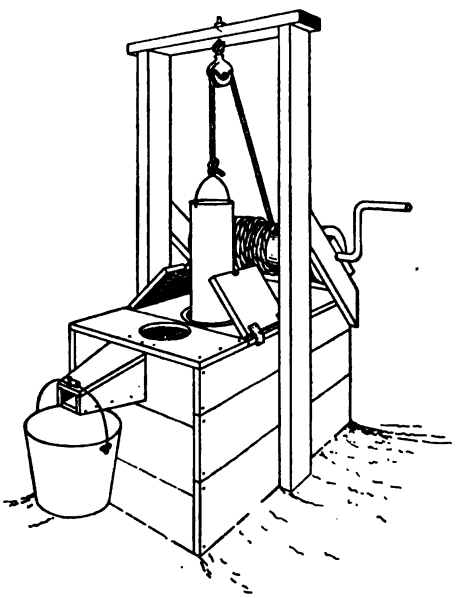


FIG. 3.—Open windlass and well curb.

In regions of high tablelands, where the wells are deep, the labor of drawing water, even by windlass, is such that hand power is replaced by horse power. Half barrels are used instead of well buckets and a boy and horse can soon draw the water necessary for the family and stock. The author has seen the old-fashioned horsepower and tumbling shaft in use pumping water for the house and for irrigation.

The windmill has long been the popular means of raising water for domestic use and for watering stock, and now, in addition, it comes to enjoy the recognition it deserves as one means of irrigating land where other means are wanting. It is the windmill which has enabled the farmer to introduce into his home some of the modern conveniences of the city. Thus one finds farmhouses supplied with hot and cold water, with bath, lawn sprinklers, and fire protection, and that, too, more cheaply than in a city home. The windmill feeds a steady stream of cold water through the milk house, and thence to the stock trough, a matter so small as to be often forgotten, yet so large as to be of great economic consequence. When the water around the milk

pans is cooled, a greater percentage of cream rises by gravity to the top. Where cool water is readily available the loss of cream may run low, but in less favored States where the water is naturally warm the loss may reach one-fifth. This, in a State whose butter products may amount to several million dollars annually, is a large sum. The difference of a single degree in the temperature of water in a State as large as Nebraska means a difference of thousands of dollars in the total dairy products. Here the windmill effects a great saving, and on well-regulated farms, while pumping water for the stock trough by way of the milk house, it may nearly pay for itself annually.

The windmill has replaced the town pump, and in villages and towns is now seen a sightly and well-kept mill and tank, supplying water to the public by the energy of the wind. (See Pl. IV, *A*.)

FIG. 4.—Partly inclosed windlass and well curb.

In supplying water for village use, pressure sufficient to throw water above the house tops may be had by placing the tank or reservoir upon high ground, or by erecting a suitable tower, which is the common method in the level prairie towns. Occasionally towers are built of exceptional height, to carry a second water tank for use in giving increased pressure in case of fire. (See Pl. XXII, *B*.)

The whirling mills are necessary accompaniments of Nebraska scenery. Their work is admirable, though impossible feats are often expected of them. As the matter of windmill irrigation is agitated the receptive mind of the progressive farmer seizes the idea. Not having experience and placing too confident reliance in the claim of the local agent, who is not a wholly disinterested party, he undertakes to raise water for irrigation from impossible depths. This must not be taken as a reflection upon the indispensable device, the windmill, which in many cases is as nearly perfect as skill can make it. The pump, not the windmill, is at fault; but the main trouble lies in the depth to water. Water can be pumped 32 feet. Below that point it must be forced, and from that point down mechanical loss increases at a rapid ratio. When one attempts to force a 60 or 70 foot column of water to the surface for irrigation his undertaking is barely within the limit of possible profit; below that point the enterprise is doubtful, if not dangerous. Farmers are urged to an immediate recogni-

A WINDMILL AND TOWER. TOWN PUMP AT VERDON, NEBRASKA.

B. EXPERIMENTAL WINDMILL AND POND ON FARM OF THE UNIVERSITY OF NEBRASKA.

tion of the chances of discouragement, failure, and loss, resulting from any attempt to force water over 70 or 80 feet for irrigation, although this will undoubtedly be changed somewhat by improved pumping devices still to be invented.

At present every community in the State can furnish examples of misguided attempts to irrigate by means of water pumped by the wind from wells of unreasonable depth. This must not place in doubt or compromise in any degree the utility of windmill irrigation, which promises to become one of the important factors in the development of the agricultural resources of the State. Already farmers are irrigating with profit from 1-acre to 50-acre tracts by means of one or more windmills. Conversation and correspondence has brought out from many farmers in semiarid and arid Nebraska the plain avowal that during the exceptional season of drought, 1893–1895, the profits from the small patch irrigated by the windmill exceeded that from the rest of the farm.

HOMEMADE WINDMILLS.

Homemade mills are, of course, of low efficiency from a physical and mechanical standpoint; yet they are capable of doing all that is demanded and more. They cost little, wear well, and do all the work that is laid on them, so that it makes little practical difference whether some of them are mills of low or high efficiency. Of all the homemade mills which the writer has visited, he has yet to hear even a mild criticism offered against one by its owner.

What a contrast may be presented by two farms—one with cattle crowding around the well, waiting for some thoughtless farm hand to pump them their scant allowance of water, the other where the cattle are grazing and the tanks and troughs are full and running over to such an extent that the hogs have their wallows to which to resort in the heat of the day. Nowhere in his travels has the writer seen empty or dry troughs on farms where the homemade mill was found.

The windmill has an important effect on population. In many homes it is professedly the sole dependence, especially so with cattlemen living in regions where grazing is the very best and where the grasses are capable of sustaining great herds free of care or cost, summer and winter alike. The prerequisite is the irrigation of one acre on which to raise garden truck for the family, and this the windmill renders possible. Without this, emigration would result, and the State would lose not only important industries, but desirable citizens with their retinue of helpers. In many places where the dairy interests are important the windmill has rendered possible the production of butter. This is noticeably so in the western or butte region along the Wyoming line. Here in one instance, in a region of bare buttes and sand hills, is a ranch with no other improvements than a low sod house, a corral, and a windmill, with a rude milk house at its base. Here is produced and sold annually $900 worth of butter (without the

burden of taxes or rent) incidental to cattle raising, which is the primary occupation.

In this same region sheep raising is an important industry. A sheep herder's camp consists essentially of a windmill and a sod house, a tent, or a covered wagon. Around each mill are several thousand sheep. On these high lands wells are deep and the hand pump inadequate. It is apparent from inquiry that the windmill decides the fate of this extensive industry, and the author has been particularly interested to note its relation to the percentage of increase in the flocks. The rate of increase reaches and occasionally passes 100 per cent where ample water is provided, and falls below 80 per cent where the mill is out of order and neglected. In their distress for water the sheep neglect and even desert their lambs. A single case may seem unimportant, but viewed as a whole by one who has seen many square miles of such surroundings and conditions, the subject is exalted, at least in the mind of the writer, to one of great importance.

So far the windmill has been considered in its relation to the necessities of life, but its relation to some of the luxuries is not unimportant. The sight of a sod house with flower beds and a lawn sprinkler is unexpected and almost incongruous. Very different from the prevailing idea of frontier life are hot and cold water faucets. With the picture of cowboy life as the half-informed press paints it one would never expect to find in a ranch house marble basins and porcelain tubs. Such things exist, and are due wholly to the agency of the wind utilized by the windmill. The barest and bleakest spot is often the site chosen for the district school, but a windmill constructed by the pupils will change this barren scene—not common to the far West alone—in five years, and in nine years the sunburned spot may be so completely reforested that the district school itself will be concealed, and the entire place and its young occupants be shaded in summer and shielded in winter.

The author would not be misunderstood. The homemade mill is not the equal of the shopmade mill. But the homemade mill is an exceedingly important adjunct to the farm, and its cheapness is such that many men who can not afford a shopmade mill are able to construct one or more homemade mills. If necessary, there may be a mill in each field or at every well on the farm. The advantage of the homemade mill is its cheapness, and unless it can be put up at a small cost it defeats its object. In many extensive frontier regions freight rates seem necessarily so high as to preclude the use of shopmade mills. Native lumber is cheap, so that the homemade mill is entirely practicable. In Arizona there is promise that important tracts of waste but rich land may come under cultivation through the agency of the Nebraska windmill. The windmills supply the only element of fertility lacking—moisture.

In many countries, old and advanced in the arts, the use of the windmill is unknown; water is raised by hand, grain is ground by horse power, by water power, and by hand, and machinery is driven in much the same way, while the wind, with all its potential energy, is neglected. Our Eastern, Middle, and Southern States would also profit by the more general use of wind power. Those States, too, must learn that water, intelligently conserved and applied to the garden, truck patch, and small fruit at the right time, means superior crops with corresponding profits. The writer believes that the people of all States should come to realize that it is a much finer boast to claim advantageous facilities for irrigation than that there is no need of it.

There is often as much need of irrigation in Ohio, Indiana, and Illinois as in Nebraska. Wherever crops are drought-stricken from time to time irrigation is desirable. It is in these very humid regions that the windmill and reservoir would be especially efficacious, for a very little water run into the furrows at a critical moment would rescue the crop. In the Eastern States, where the thin, clayey soil is not fitted to withstand drought as are the soils of the Great Plains, a reservoir of water could flush a given patch with marked success. The writer anticipates the time when the lessons of irrigation in the West will be taught in the East, not only as a means of averting failure and loss by drought, but as a means of greatly increasing the quality and quantity of the yield. The windmill is one means to this end, not to be relied on solely, but to be available in any emergency.

On the Great Plains, where humidity decreases as rapidly as evaporation increases and where the available surface water is limited and the wind must be depended on, the windmill becomes a necessity. In traveling through Kansas and Nebraska 20 or 30 mills may be easily counted at one time from the car windows. At first the author believed that the windmill stimulus here was the product of necessity during recent years of drought, but he finds that more mills, both homemade and shopmade, have been going up during the present humid years than before. They are used as luxuries rather than necessities, and the present inference is that these winged specters are harbingers of prosperity.

At certain times and in certain places, however, they are still necessary, especially toward the less humid portions of the State, particularly in the broad river valleys, where wells are shallow and the supply of water inexhaustible. The rivers of Kansas, Nebraska, and the Dakotas are numerous, and some of them are important, but they are steadily being diverted from their channels into the irrigation ditches of States to the west. The total available surface supply is barely sufficient for the irrigation of 6,000 square miles out of nearly 77,000, one-half of which would be greatly benefited by irrigation. Recourse must be had, then, to such other means as superior cultivation, or

soil culture, for the catchment and retention of moisture; the impounding of water in ponds, lakes, draws, and canyons; tunneling into the sand hills and buttes; tapping the underflow of rivers; and raising water by means of current wheels, and by pumps driven by some motive power, preferably the wind. This outlook has given the windmill increasing notice of late.

COST.

The homemade windmill is supposedly built during unemployed hours by the owner or by his sons; so the cost of labor is not reckoned in these estimates. Old wire, bolts, nails, screws, and other odds and ends of hardware, old lumber, poles, and braces such as are common to every farm, enter largely into its construction. Even neglected mowers, reapers, and planters, old buggies, and wagons contribute material. Here are to be found good journals with oil cups, cranks, sprocket wheels, and chains, gear and bevel wheels of various combinations. The farmer who is inventive enough to build a mill is competent to see quickly the adaptability of certain parts to his ideas. It is this use of old and neglected material which is particularly recommended in this connection, for in making a mill of low efficiency, such as most homemade mills are, cheapness is the main object. Many mills have cost nothing whatever. Others cost $1, $2, and $3, and occasionally as much as $50, $75, and even $150. The average mill, such a mill as is needed for ordinary purposes, can be built for $2.50, which is an average from a large number, and its cost should not, and seldom does, reach $10. The writer considers $3 a liberal allowance for everything needed on the ordinary farm for the construction of a strong, satisfactory, and lasting mill large enough to pump for the house or stock. Such a mill, if rigidly made—inattention to this matter being the cause of more accidents among homemade mills than any other—ought to stand five or six years of uninterrupted service.

CLASSIFICATION.

However modified to suit the fancy and caprice of various builders, the mills may be divided into four groups: Go-devil or jumbo mills of the overshot type; merry-go-round mills; turbine or opened-faced mills, including battle-ax, Holland, and mock-turbine mills; and reconstructed mills. These may be tabulated as follows, in inverse order of efficiency:

Classification of the principal types of homemade windmills in Nebraska.

- (1) Jumbo mills (see page 35)
  - Baby jumbos.
  - Medium jumbos
    - With 4 fans.
    - With 6 fans.
    - With 8 fans.
  - Giant jumbos.
  - Screw jumbos.
- (2) Merry-go-round mills (see page 44)
  - Unmounted.
  - Mounted.

- (3) Battle-ax mills (see page 47)
  - With 2 fans.
  - With 4 fans.
  - With 6 fans.
  - With 8 fans.
  - Giant mills.
- (4) Holland mills (see page 54)
  - With 4 fans.
  - With 6 fans.
  - With 8 fans.
  - Giant turbines.
- (5) Mock turbines (see page 56)
  - Set turbines.
  - Revolving turbines.
    - Without rudders.
    - With rudders.
- (6) Reconstructed turbines (see page 64).
- (7) Shopmade turbines (see page 65).

DISTRIBUTION.

Nebraska seems to be the heart and center of the windmill movement. The famous Platte Valley, with its broad expanse and shallow wells, is a veritable windmill arena. From Omaha west through the State, a distance of 500 miles, and even beyond to Denver, there is a constant succession of these creations of a sturdy population.

During the summer of 1897 the writer engaged the services of three students, who were provided with teams, saddle horses, camp wagons, cameras, and camp accouterments in general, and drove from Lincoln to Denver, following roads south of the Platte going and north of the Platte returning. They found these unique and interesting mills everywhere. Going over the same ground in person the following year eight to ten mills were commonly found clustered about a town, each widely separated town having a dominant or prevailing type. Sometimes the mills were found on every farm and were too numerous to visit and report on. They are also found in the Republican Valley and the valleys of the Loup rivers and their tributaries. The State rises gradually from 900 feet in southeastern Nebraska to 5,300 feet in the butte region of the western boundary line, where the wind is often unreliable over considerable tracts, so that difficulty is experienced in running the most approved steel mills. The distribution of homemade mills is confined chiefly to river valleys and to certain sand-hill regions, where wells are shallow.

JUMBO WINDMILLS.

This is the lowest form of windmill. The jumbo, also known as the "paddle wheel" and the "go-devil," is simply an overshot wheel which bears the same relation to the air that the overshot wheel of hydraulics does to the water. It is a stationary mill, consisting of four or more paddles fastened to a horizontal axis set squarely across the direction of the prevailing wind, with the lower half boxed in. The smaller mills of this type are appropriately termed "baby jumbos." The larger jumbos are planted on the ground and baby jumbos on towers or buildings.

Being mills whose method of construction is obvious, they are favorites, particularly in the portion of the State lying east of Grand Island. West of that point the jumbo is usually replaced by the battle-ax mill, which the author considers a superior type. The jumbos are mills of low efficiency, but that matters not in the present discussion. They are efficient enough for all practical operations; that is the real question here, and theoretic considerations may be fittingly postponed. Those who have decided preferences for the jumbo need not fear disappointment. If the mills are well built they give satisfaction. If poorly made their efficiency may run as low as 15 or 20 per cent; but if built on the most approved plan they may register 40 per cent, as Professor Hood[1] has shown. In practice the poorest can pump a great deal of water, probably more than the ordinary family will use. In this connection it may be well, for the sake of comparison, to state that the efficiency of a good shopmade mill is at least twice as much as that of the jumbo, but the cost is ten to twenty times as much. For the capital invested the jumbo is probably more efficient than the best steel mill. The jumbo gives from one-eighth to one or two horsepowers, more or less, according to the wind, the size of mill, and other modifying conditions.

Professor Hood and his students in testing a 14-foot eight-fan jumbo found that in a good breeze it gave from one-tenth to one-fifth of a horsepower, and in a 38-mile wind it gave 1 horsepower. The power will vary according to the construction and position of the mill, and according to the wind and other factors. In Nebraska and Kansas the shafts of jumbos stand east and west, so that the fans may be struck by the prevailing wind, which blows from south to north, or at times in the opposite direction. The jumbo runs equally well whether the wind is from the north or south, but is motionless in an east or west wind. If from the intermediate points of the compass, the fans are, of course, struck obliquely, but not altogether ineffectually. This virtually covers all winds, except rare and exceptional ones; hence daily working is assured, regardless of shifting winds. Nevertheless, some take the precaution to build jumbos with spiral or screw fans, in which event they do good service with winds from any quarter.

Jumbos are not wholly ornamental, but that is unimportant. The jumbo has served useful purposes on hundreds of frontier homes, and has many undeveloped possibilities awaiting the genius of succeeding generations of farmers. The average cost of such mills is about $4, and they are sometimes used to singular advantage. Such mills, veritable toys, which cost nothing whatever, and were built in play by boys on the farm, have been put to work in earnest pumping water for the stock.

[1] New tests of certain pumps and water lifts used in irrigation, by O. P. Hood: Water-Supply and Irrigation Paper No. 14, U. S. Geol. Survey, 1898.

A. BABY JUMBO WINDMILL ON GOODRICH FARM, NEAR BETHANY, NEBRASKA.

B. BABY JUMBO BUILT BY J. L. BROWN, KEARNEY, NEBRASKA.

BABY JUMBO WINDWILLS.

The baby jumbo on the Goodrich farm, near Bethany (see Pl. V, *A*), is one of those referred to. It stands about 12 feet high, on the abandoned support of an old tank, and pumps water for the stock. Old parts from a discarded self-binder were ingeniously adapted to the existing needs. This small mill, with arms 2½ feet long, with four board fans each 4 feet long, and geared by sprocket wheel and chain in the ratio of 2 to 1, cost nothing, and pumps from an ordinary well water enough for the stock. This is an attractive and showy little mill, especially to those who are studying such matters, and is a credit to the boys who built it; it is introduced here, however, to show what can be done in this line rather than to encourage mills of this size or of this particular make. It is only a toy, but boys who can build one of this size are capable of building a larger one and of constructing it on approved lines if models are before them.

It is a safe assumption that, having at hand illustrations and descriptions of various windmills suited to home construction, many idle moments would be profitably employed in this work, both by men and boys on the farm and in the villages. Accordingly numerous examples, seemingly repetitions, will be reproduced in order that each prospective builder, without compromising his own individuality and personality, may have the right of accepting and rejecting plans, so as to embody in his own designs the desirable features of others.

The baby jumbo on the Goodrich farm was considered the smallest of its kind, but before a description of it could be penned a mill smaller by 1 foot, which, however, stands on a higher base, was found in the neighboring town of Havelock. This baby jumbo, built by Mr. W. W. Iler, has four fans 3 feet long, with arms 2½ feet long. It is attached by a 16-inch crank and rod directly to the handle of the pump. In a good wind (probably a 16-mile wind) this little mill, perched on a tower 16 feet high, discharged from a 60-foot well 400 gallons of water in forty minutes, or at the rate of 10 gallons per minute, as measured and reported by the owner. It supplies water for a boarding house and for the stock and cost only $3.70.

The remarkable little jumbo designed and built by Mr. J. L. Brown, proprietor of the Midway Nursery, 2 or 3 miles east of Kearney, Nebraska, is shown in Pl. V, *B*. It cost only $1.50, but pumped sufficient water to irrigate and save the garden truck, the strawberry patch, and the small fruit during the most trying season of drought recorded in the State. This is a surprising record for so small a mill, but it was carefully planned and well built. Differing from the ordinary proportions this mill is higher than broad. Its box is 3 feet wide, 9 feet long, and 6 feet high, with fans mounted on a gas-pipe axis. The axis and its crank, cost $1.50, while the rest was made out of the sides and ends of old coffee boxes, in accordance with the rule: Build

the jumbo cheaply or not at all. It is connected with the pump by a lever arranged in the ratio of 5 or 6 to 1. While means were not at hand to test this mill, in a good breeze it pumped water and was probably not overloaded by the weight of 200 pounds.

The practical benefits resulting from the mill are indisputable, and are well expressed by Mr. Brown, its builder, who says that the profits from the mill during the three years of drought and crop failure exceeded that from the rest of the farm. The claim is not that the profits are great, for such can not be expected from a small mill and about an acre of garden; but when this is all that is left it becomes relatively large. Let no one be deceived by this and grow too sanguine and overexpectant. The mill may not net its owner over $100, but if the rest of the crop is a total failure, this is worth more than one hundred cents per dollar. A case is known of a cucumber patch saved by a small stream from a windmill. This patch netted its owner $100 for pickles, cut and marketed during the month of September. The mill may easily exceed the profits of the rest of the farm during exceptionally poor seasons. The windmill is not the redemption of agriculture, but is an important aid at all times, and sometimes the only source of revenue.

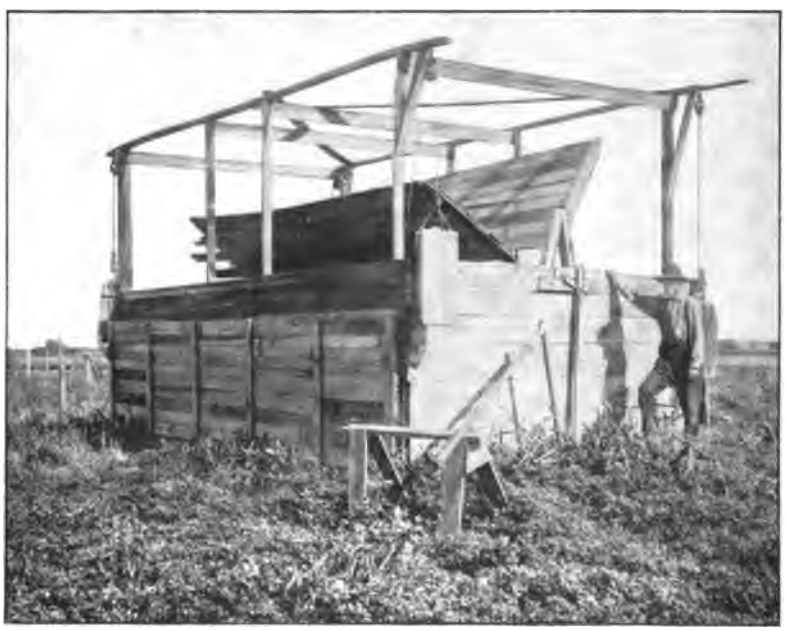
This mill teaches a timely and suggestive lesson in economy in such work. Here by the exercise of a little foresight in securing an occasional packing box instead of lumber, an excellent mill was produced at a nominal cost, and could have been built without outlay by adapting an iron axle from some farm implement. This goes to show that baby jumbos, large enough to pump for the house, barnyard, and stock, are within reach of the poorest. The young farmer can often profit by picking up, almost at his own price, discarded wagon axles and old rods of iron, which are common at the village blacksmith's or at the city junk shop. A buggy or wagon axle, with the hubs or thimbles used for journals, will prove especially convenient to prospective builders.

JUMBO WINDMILLS OF INTERMEDIATE SIZE.

Baby jumbos are the least efficient of the homemade mills. Those of intermediate size, such as are commonly built by farmers and small market gardeners, will now be considered. These mills average about 8 by 12 feet; some cost nothing, others $6 to $8.

A good example is furnished by Dr. Boardman's jumbo mill on the edge of Overton. This mill was built to replace an old one put up three years before, and it was not necessary in this case to study strict economy either in the use of help or in the purchase of material. Good, new lumber was purchased, and a carpenter and smith engaged to do the work. When finished, this mill, with a box 6 by 12 feet, supporting four fans on an iron axis, each fan 5 by 6 feet, with a radius of 6 feet, was capable of supplying water for 100 head of stock; its cost was $8. The same mill could have been built by a man of

A. MEDIUM-SIZED JUMBO WINDMILL IN GARDEN OF M. J. OLSON, COZAD, NEBRASKA.



B. LARGE JUMBO WINDMILL AT CUSHMAN PARK GARDENS, LANCASTER COUNTY, NEBRASKA.

Size of mill 20 by 14 by 14 feet.

A. JUMBO WINDMILL (NO. 1) IN TRAVIS GARDENS, NEAR LINCOLN, NEBRASKA, SHOWING PORTION OF RESERVOIR.

B. SCREW JUMBO WINDMILL.

Photographed from model built by the author.

limited means for $2 or $3. Had it been a mill of six fans instead of four, it would have been a good model for others. It is a good mill, serves its purpose, satisfies its owner, and according to his estimate will pump water for 100 head of stock and continue in good order for five years or so to come. At that rate he is paying for his water service scarcely more than $1.50 a year.

The trouble with all four-fan mills is that but one or at most two fans are in the wind at any one time, while the six or eight fan mills may expose three or four times the surface to the impact of the wind. Accordingly, if other things are the same, the mill with more fans is apt to respond more readily to light winds.

Comparable with this, in point of size, is the mill of Mr. W. W. Goodrich, at Bethany, shown in Pl. VI, which he believes was unnecessarily well made. Extra expense was incurred by purchasing a hardened Damascus steel axis, with good bearings and oil cups, which cost $5, and made the mill when complete cost $8. It has six fans, each 9 feet long, with a radius of 5½ feet, mounted on a box about 9 by 11 feet and 6 feet high. As the fans revolve there is a resisting cushion of air in the box, which must in a measure retard the fans. To overcome this the designer has raised the mill above ground, and has made the bottom movable in two parts or doors, which can be lowered to allow the escape of compressed air when the mill is revolving rapidly. When the wind is from the south the north door is opened, and vice versa. Mr. Goodrich says that a gas-pipe axle would serve his purpose as well as the more expensive steel one, and that with it he could build the same mill for $4. The baby jumbo on this farm, already described, pumps for the stock. The medium-sized mill irrigates a portion of a 6-acre tract set with egg plant for the Lincoln market. Mr. Goodrich has gone to considerable expense in attempts to raise water by horse power for the improvement of his farm, and especially for his extensive market gardens, and the present experiment is an attempt to use the wind as a much more economical means to that end.

At Cozad there is a jumbo of medium size, which is sensitive to light winds and is used in irrigating the market garden and small fruit of Mr. M. J. Olson (see Pl. VII, *A*). The box, which was about 9 by 13 by 6 feet high, carried six fans, having a radius of 6 feet and a length of 8 feet, mounted on a 1-inch iron axis with metal bearings and oil cups from old machinery. A 12-inch crank with friction roller was attached to the longer arm of a lever, 9 feet long (as shown in fig. 5), the shorter arm, 6 feet long, being attached to the pump rod. It pumps water with a 16-inch stroke from an 18-foot well with 3-inch casing without cylinder. It has pumped 1,200 gallons in an hour, as measured by its owner. The mill and all incidentals cost $20.

The jumbo may be constructed out of almost any waste or idle property. The axis may be of wood, gas pipe, or solid shafting, and the framework may be of poles cut from the place, the box of old lumber,

the sails of duck, burlap, sheeting, fencing, weatherboarding, store boxes, barrel staves, or old tin and sheet iron. All these adaptations are seen.

Two jumbo mills on the market garden of the Travis Bros., of Lincoln, afforded the writer an opportunity to see the workings of these

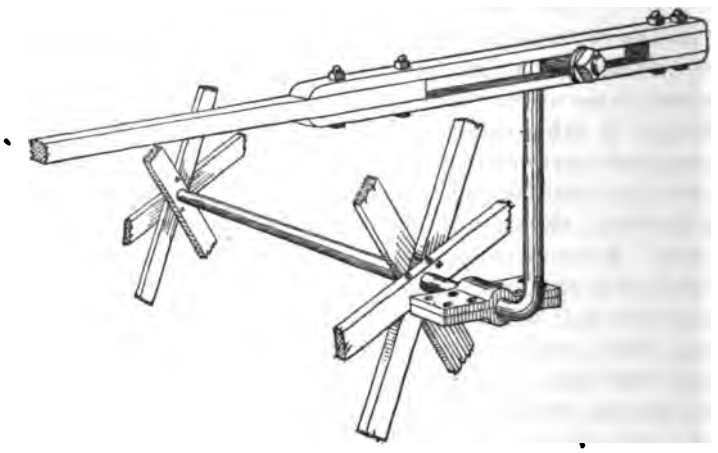


FIG. 5.—Jumbo windmill of M. J. Olson, Cozad, Nebraska, showing 9-foot iron axis, 2 by 4 inch arms, journals, 2-foot crank, and walking beam.

mills and their practical results. Though hastily and poorly built, they demonstrated their usefulness, and are easily worth their cost. One cost $8, the other $11. The two mills irrigate, as far as it is

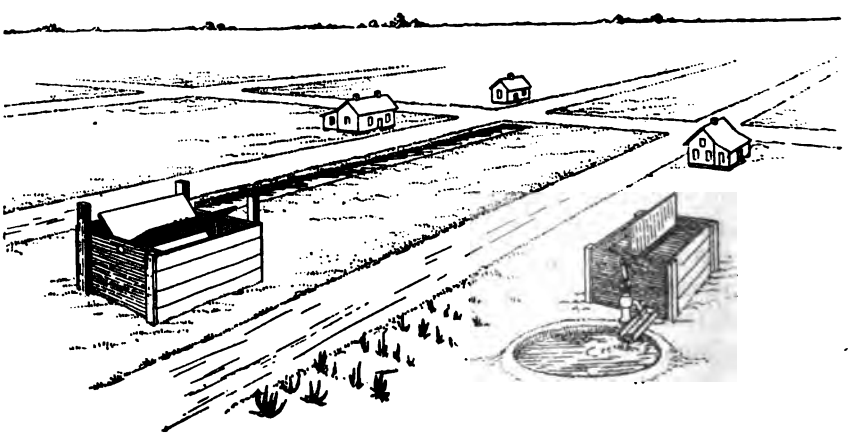
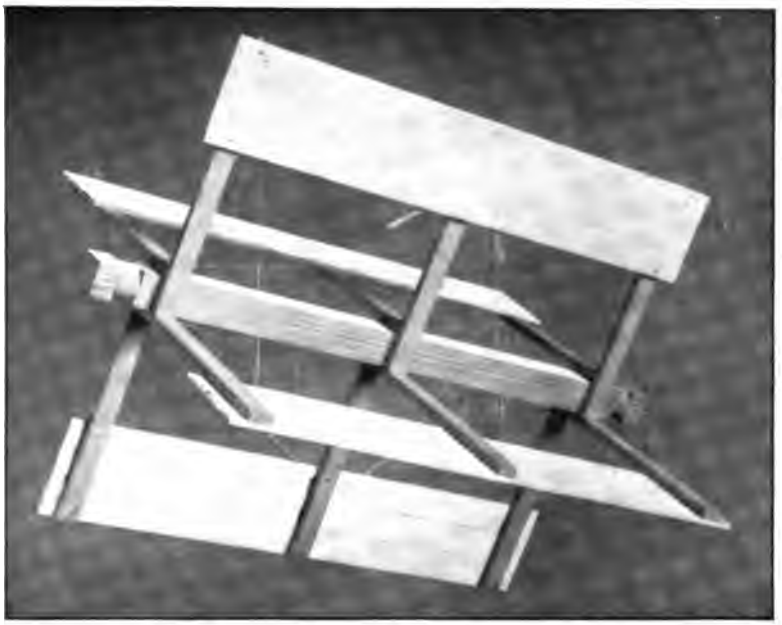


FIG. 6.—Jumbo windmills and reservoirs in the market gardens of Travis Bros., Lincoln, Nebraska.

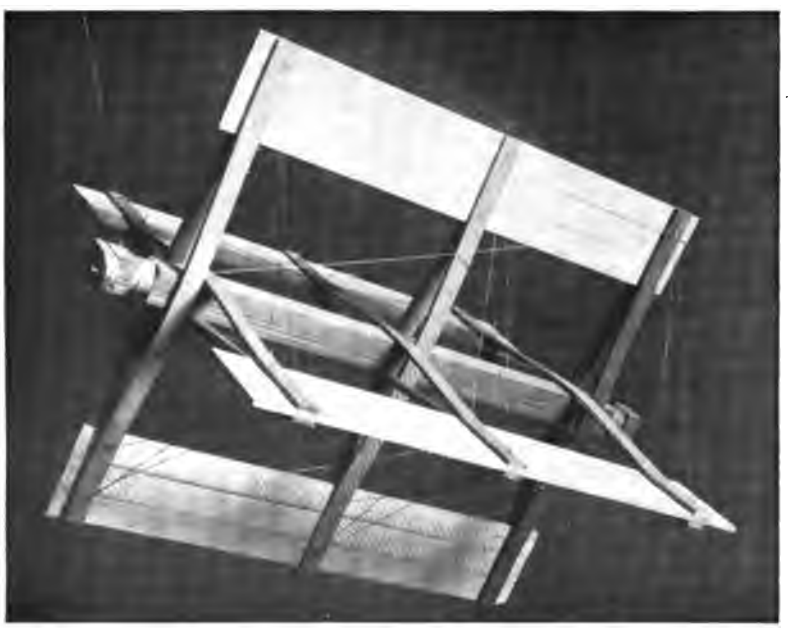
desirable to irrigate in this region, about 8 acres of garden. According to the gardeners the yield was ahead of the demand of the market.

Mill No. 1 (shown on the left in fig. 6), with a box 9 feet wide, 13 feet long, and 8 feet high, carries four fans of burlap, each 9 by 4 feet, stretched on arms 6½ feet from the center, and pumps water into a long,



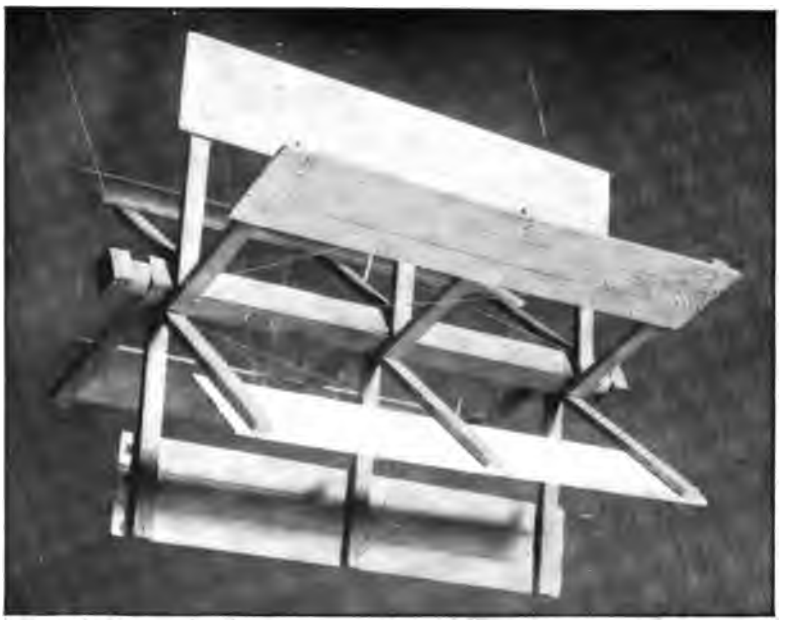
A. METHOD OF ATTACHING ARMS OF JUMBO WINDMILLS TO AXIS.

Photographed from model built by the author.



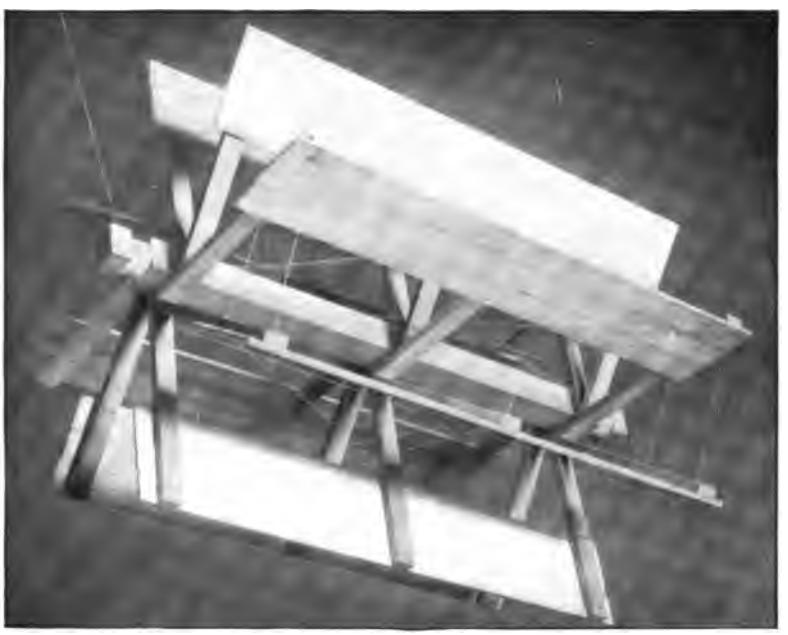
B ANOTHER METHOD OF ATTACHING ARMS OF JUMBO WINDMILL TO AXIS.

Photographed from model built by the author.



A. METHOD OF CONSTRUCTION OF SIX-FAN JUMBO WINDMILL CROSS-BRACED BY TWISTED WIRE.

Photographed from model built by the author.



B. METHOD OF CONSTRUCTION OF EIGHT-FAN JUMBO WINDMILL CROSS-BRACED BY TWISTED WIRE.

Size: 12 to 14 feet long, 10 to 12 feet in diameter. Photographed from model built by the author.

narrow reservoir, 150 by 4 by 2 feet deep, skirting the higher edge of a 5-acre patch. The grade was such that the rows of vegetables were quickly flushed with water when necessary. At the four corners of the box are four uprights or standards, carrying on top a pulley with rope attached to a sliding cut-off or wind guard, to be raised and lowered in adjusting the mill to winds of varying velocity. These guards, constructed on a wrong plan, greatly increased the expense for lumber. Mill No. 2 (shown on the right in fig. 6), of about the same size, cost $11, and irrigates an adjoining 3-acre tract successfully, but is capable of doing more work.

In the case of these two mills a defense is found for the adoption of the cheap homemade mill. The position of these two gardens in the outskirts of Lincoln made two mills necessary. The enterprise was in the nature of an experiment; accordingly from a business standpoint it was assuming much less risk to erect two cheap mills than to put up two steel mills, each of which would probably have cost twice as much as the two jumbos together. If successful when well established and past the experimental stage, the enterprise may deserve a better type of mill, whether homemade or shopmade. (See VIII, *A*.)

The argument for the jumbo on the ground of experiment is further exemplified in the case of the John Tannehill nursery and garden at Columbus. Finding that his orchard thrived and that it was well set with fruit, which, however, fell off before reaching maturity, he inferred that this was due to insufficient moisture, and proceeded to experiment by building a large jumbo, which has become a sort of landmark. It is a large mill, capable of driving two 6-inch cylinders and of irrigating about 10 acres of orchard. It is built on approved plans, especially with respect to the fans. The six 16-foot fans have long arms (9 feet), not boarded up solidly, but with a space below for the "dead air"—that is, the air which has struck the fan and used up its energy. The object is to get rid of this as quickly as possible, thus making room for fresh air with unexpended energy. There are six fans, well bolted, wired, and braced, mounted high on a box, substantially made and securely anchored. The mill pumps water into a reservoir, from which it is drawn off to irrigate the orchard.

This experiment, which cost $100, was a success. By artificially supplying a little more moisture the orchard holds and ripens the fruit which formerly dropped off prematurely.

SCREW JUMBO WINDMILLS.

The screw jumbo (see Pl. VIII, *B*) is of rare occurrence, the author having found but two in the State—one at Trenton, Hitchcock County, and the other at Ainsworth, Brown County. While it is altogether probable that they are not so efficient as their enthusiastic builders believe, they are successful and are not lacking in interest to the student of windmills.

Perhaps one claim to superiority is well grounded. The screw jumbo—also known in the vernacular of the Great Plains as a "regular stem-winder"—receives wind from the east and west almost as well as from the north and south. Their builders say that they respond to wind from every quarter. The sails, which are of duck, although thin wood might be used, are not stretched on a line parallel with the axle, but pass diagonally from one arm to that next behind it, and so on, producing a twisted or auger-shaped effect in the mill. The claim that the mills run with great steadiness is doubtless true, for it is readily seen by a glance at the cut that each fan receives the advantageous wind progressively throughout its entire length, and that the fans are not alternating between advantageous and disadvantageous positions in the wind. A glance will be sufficient to show that some position of the fans will be struck, no matter in what direction the wind may blow. The boxes for screw jumbos are boarded up on the sides, but left entirely open at the ends.

CONSTRUCTION OF JUMBO WINDMILLS.

The jumbo, as before stated, is a mill of low efficiency at the best, a fault made more pronounced by careless construction, lack of rigidity, and poor anchorage. The mill, as well as the farm sheds and outbuildings, should be strong enough to weather the blast and storm. Lack of rigidity is another fatal oversight. The round wire nail when first driven home seems strong, but constant vibration may draw it slightly, or the hole may be enlarged so as to allow too much play, foreshadowing ultimate destruction. This may be avoided by the use of an occasional bolt. Bolts are cheap and may be obtained at any hardware store. The fans should be bound together by fencing wire, rendered taut by doubling and twisting. Good anchorage is readily obtained by burying posts with crosspieces on the bottom and stamping the earth firmly around them. These measures of precaution should always be observed, especially in the case of large mills. The probability of failure and disappointment should be forestalled by rejecting the popular four-fan mill and accepting the six or eight fan design instead. One of the worst errors of construction

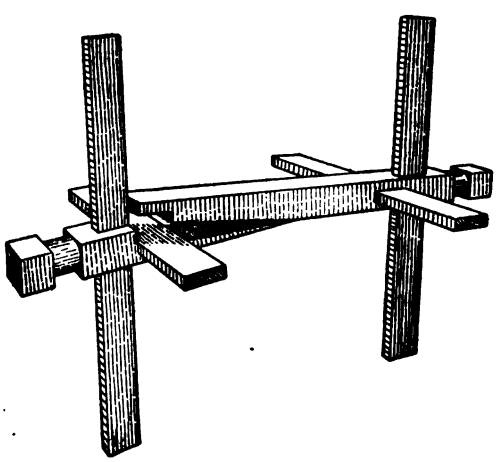
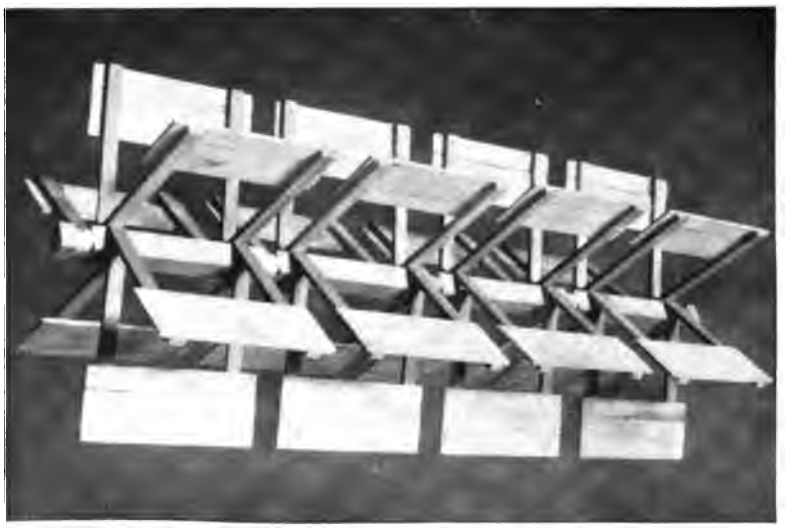
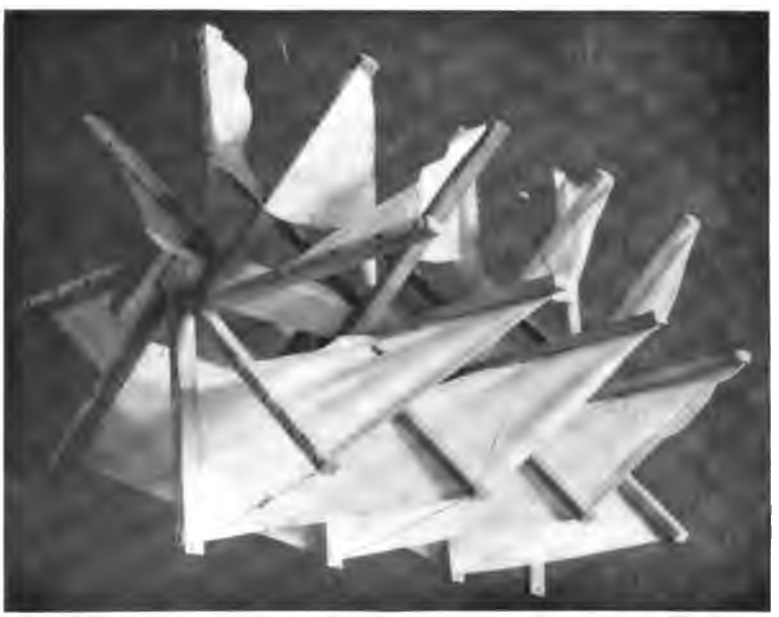


FIG. 7.—Break resulting from improper method of fastening jumbo windmill arms on the axis.



A. METHOD OF CONSTRUCTION OF GANGS OF JUMBO WINDMILLS.

Photographed from model built by the author.



B. METHOD OF CONSTRUCTION OF SCREW JUMBO WINDMILLS, WITH CANVAS SAILS AND ARMS BRACED WITH TWISTED WIRE.

Photographed from model built by the author

A. GANG OF JUMBO WINDMILLS ERECTED ABOVE CORNCRIBS OR SHEDS.

Photographed from model built by the author

B. JUMBO WINDMILL WITH WIND GUARD OR CUT-OFF.

Photographed from model built by the author.

is to weaken a part which is subject to stress and strain. An example of this is found in the way holes are mortised through axes for the arms, as shown in fig. 7. When an 8 by 8 inch axis, having a span of 18 feet, is cut through at each end to admit 2 by 4 inch arms, it is disqualified for long use.

Methods of attaching the arms are shown in fig. 7 and Pls. IX, X, XI, which are self-explanatory. When loaded down with heavy arms and fans it is a severe test for any stick of timber or gas pipe or shafting to span 15 or 18 feet. Accordingly the author proposes what he may call twin, triplet, and quadruplet or multiple jumbos. By this means a jumbo of any length and of almost any strength is possible, for the axis has support every 8 or 10 feet. (See Pls. XI, *A*, and XII, *A*.) This, the writer believes, is the means of making powerful jumbos, especially if a chain and bucket are used instead of a pump. In regions of shallow wells these gangs of jumbos might be used for irrigation on a larger scale than is possible with the ordinary jumbo.

It seems so essential that the jumbo should be cheap that the author would minimize expense by doing away with the box and by adapting sheds and buildings to this use. Every well-regulated farm has its complement of sheds. It will cost no more to arrange them with reference to carrying the fans of a jumbo or multiple jumbo. Corncribs which are built in pairs facing each other with a driveway between seem suited to this purpose, as shown in Pl. XII, *A*. In the mill illustrated the fans are slowed down by a brake and are then tied, as is the common practice. In this case the cut-offs or wind guards are omitted, it being assumed that the mill is well enough built to resist storms and wind. Rafters could be extended to support the axis. The labor and expense in that case would be confined to the construction of the driving parts or fans. Many mills could be built without cost. By the multiple plan mills might be built of sufficient strength for shelling and grinding as well as for pumping.

Many men increase the cost of their mills by wind-breaks, guards, or cut-offs in use. Some allow their mills to run in whatever wind blows, others adjust breaks in such a way as to regulate them, others build sliding guards, which run up and cut off the wind wholly or in part, as need be. The author would suggest that it is as easy and less expensive to let the sides of the box itself be adjustable, as shown in Pl. XII, *B*, instead of building cut-offs, one on the north side and the other on the south side of the box. If balanced, the sides could be raised and lowered with little exertion. Or, simpler still, the north and south sides of the box might be hinged so as to be let down; then the wind, striking equally against the top and bottom fans, would stop them. If objected to on the ground that the fans thus unprotected are exposed to too much wind, it may be rejoined that there is no reason why they should not be made strong enough to resist it as

easily as the cut-off. One could check the mill or stop it outright, according as he lowered the door a little or dropped it flat.

The arms should be of good length, say 5 to 7 feet, thus securing leverage with light fans, which seems better than to use a fan of less radius and greater length and weight. The fans should cover about one-third of the length of the arms. If the axis is of wood it must be rounded at the bearings, care being taken that as little as possible be cut away, otherwise the axis will be weakened. The crank is easily made, and if the size of the mill warrants it there should be one at each end. Some prefer wood, others metal; it is a matter of indifference which is used, so that it is rigid.

PUMPS.

Mechanically the best pump is faulty. Other things being equal, the endless chain of buckets is doubtless better. Here the pressure is not intermittent, but is constant at all times. These buckets are adapted to sprocket wheel and chain, and where the lift is not too great these are to be recommended. The pump, however, is the familiar water lifter and the one generally adhered to. When the mill is large enough to warrant it, two pumps of sizes suited to the mill should be used, but it should be remembered that it is probably as great waste of energy to overload as to underload the mill.

MERRY-GO-ROUND WINDMILLS.

Windmills of all makes have natural limitations, and the merry-go-round is a realization of an attempt to devise mills of unlimited size and strength. The larger ones are of rare occurrence, but are seen in several parts of the State. The smaller ones are mounted on towers, the larger ones on the ground, as shown in Pl. XIII. The former are the more common and look like elevated water tanks, for which they are often mistaken.

FIG. 8.—Hooded merry-go-round built by William Winn, Berwin, Nebraska, showing semicircular hood on rollers guided by large rudder.

The fans revolve about a vertical axis, and surrounding all is a series of movable shutters, which come together and form a sort of closed cylinder when the mill is out of gear. When in action they are partly opened, admitting air to the fan on one side and excluding it from the other. But these are quite as limited in size as other mills, and so defeat one important purpose of the merry-go-round. This kind, which is

SMALL MOUNTED MERRY-GO-ROUND WINDMILL NEAR LINCOLN, NERRASKA.

taken as the lowest of its order, is generally small, perhaps 6 to 12 feet in diameter and 6 to 12 feet high, exclusive of the tower. It is of doubtful efficiency, though in active operation, and is intricate enough to require skilled labor and expensive material, which in part unfits it for general adoption. One seen at Grand Island, on the farm of Mr. Henry Joehnck, when built fourteen years ago, rendered important service in irrigating garden truck for the Grand Island market. At Greeley Center a similar mill, 20 feet in diameter, is used for grinding, there being a lack of water power.

The merry-go-round mill of Mr. William A. Winn, of Custer County, consists simply of a series of fans radiating from the central axis. Around the same axis revolves a great semicylindrical hood or cut-off, shown in fig. 8, running on friction rollers and guided automatically by a large vane. When in action half of the fans are exposed and half protected, as shown in plan (fig. 9). The mill is thrown out of the wind by swinging the shield fully around in the direction from which the wind comes, thus covering all the fans.

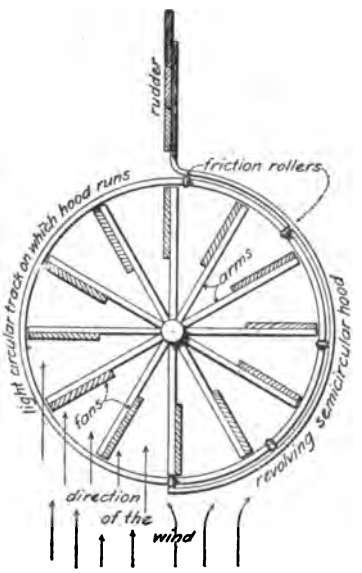


FIG. 9.—Plan of hooded merry-go-round windmill built by William Winn.

These are mills capable of many modifications and adaptations. They are easily built, braced, and supported, and no mill perhaps lends itself more kindly to unlimited extension, all of which should bring them into prominence that they have not yet enjoyed; important results may be expected from these mills. This type of mill is worthy of development.

In western Nebraska, near the Colorado line, where the precipitation runs as low as 12 to 15 inches and evaporation as high as 6 feet, irrigation begins to be imperative. Here 10 acres have been successfully irrigated by Mr. E. E. Blackman's merry-go-round, and this is more of a test than it would have been in a more humid portion of the State. This mill, as he describes it, is 24 feet in diameter and carries numerous swinging door-like fans of light wood 6 feet high by 4 feet wide. The fans are free at one edge, as shown in plan in fig. 10, and, like a flag floating from the mast, they swing edgewise against the wind, this being the line of least resistance. But the moment the center is passed each fan in turn swings back against the immovable arms and exposes its 24 square feet of surface to the impact of the wind. Half of the fans are continually in the wind and half out of it. Such a mill, well made, might be an

engine of strength, but careful work and well-considered plans are necessary to avoid resistance and loss of power. Mr. Blackman insists that this is the cheapest and most efficient mill for its weight that can be built. His mill cost $4.75, exclusive of home labor, pumps an 8-inch stream, and irrigates 10 acres.

A similar, though larger and much more elaborate mill, designed and built by Mr. S. S. Videtto, may be seen on a ridge near Lincoln. (See Pl. XIV, *A*.) The mill is probably 40 feet in diameter and 12 to 14 feet high. It runs on a circular steel-rail track, and is connected by cogwheels to a tumbling shaft which drives the pumping machinery.

These mills are broad of base, and correspondingly stable. There is no apparent limit to their size, and they may embody important ideas.

It is certainly desirable to have some powerful windmills, and the author has designed several which, though too large, perhaps, to be practicable, were conceived in the hope that some available means of raising the underflow waters of the Platte and other rivers might yet be found. Here, at a depth of 4 or 5 feet in coarse pebbles, is an inexhaustible supply of water, of which but meager use is made. The advent of a good water lifter will revolutionize all this. At present but an occasional seepage or underflow ditch is dug, such as the Gould-Hollingsworth ditch at Ogallala. The trouble lies not in the supply, but in the fact that one must go upstream 4 or 5 miles to get the required fall. For private ownership the expense is often prohibitive. It requires no engineering feat to devise and construct windmills powerful enough to do this work, and the author confidently hopes for its realization.

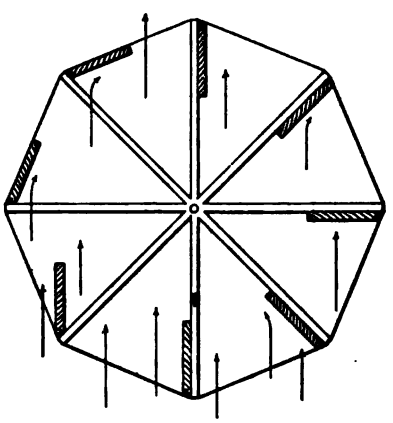
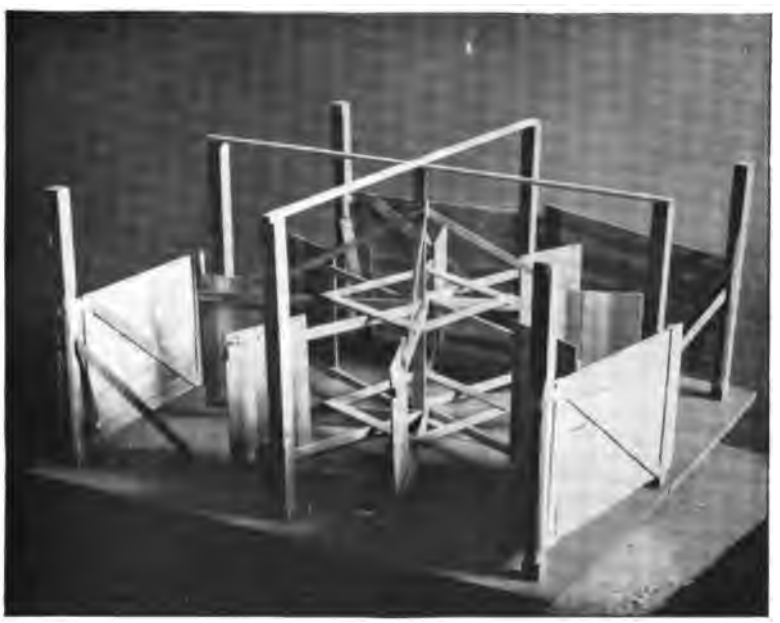


FIG. 10.—Plan of large merry-go-round windmill of E. E. Blackman.

The merry-go-round, when perfected, gives great promise. In the construction of these mills the importance of rigidity is again to be emphasized, for especially light material enters into their make-up. Bolts and twisted wire should be used freely. Where cogwheels and shafting are not at hand, they can be obtained in the market. The axis may be a suitable pole cut from the place and guyed securely by wires in several directions, and the mills may be so set between sheds as to shield part of the fans; or swinging doors, as shown in Pl. XIV, *B*, may be used to possible advantage. They may also be mounted on sheds. The arms ought to be made of new lumber, but packing

A. MERRY-GO-ROUND WINDMILL BUILT BY S. S. VIDETTO, LINCOLN, NEBRASKA.



B. SUGGESTED FORM FOR EIGHT-FAN MERRY-GO-ROUND WINDMILL.

Photographed from model built by the author.

boxes would furnish material good enough for the fans, which may be made of wood, duck, or sheet metal. Pl. XIV, *B*, illustrates an eight-fan merry-go-round windmill designed by the writer. The diameter is 20 to 25 feet, and the fans 6 to 9 feet. Four gates or wind guards, each of which is so hung upon the corner post as to swing through 270°, easily throws the mill in or out of action. The high-geared wheels and shafting below are not shown.

OPEN-FACED OR TURBINE WINDMILLS.

Open-faced or turbine mills may, for convenience, be divided into five distinct kinds, as follows, arranged in inverse order of their importance: Battle-ax windmills, Holland windmills, mock turbines, reconstructed turbines, and shopmade turbines.

These are the windmills of preeminent importance. They represent the most specialized type of windmill, and the man who is about to construct a mill of some other form, though in great favor locally, may well afford to consider the possibilities which this kind of mill affords. The simpler mills are easily constructed, and are inexpensive, efficient, and altogether superior, in the estimation of the writer.

BATTLE-AX WINDMILLS.

In its simpler form this mill consists of a tower for the support of a horizontal axis and crank, to which arms are attached bearing at their extremities fan-like blades, which have a real or fancied resemblance to a battle-ax; hence the name.

Justification for this is found in the fact that the arms—which are the handles—each carry a fan, shaped in some instances like a battle-ax. It is certain that their keen edges cleave the air in a belligerent fashion. When viewed from the side an optical illusion is produced, and these revolving blades seem to be slashing wildly at space in opposite directions. However, they fight their way through, and are victorious mills, worthy of praise.

Like the jumbo and set turbines, the battle-ax mill has its axis set in the direction of the prevailing wind—that is, north and south. The axis may be of wood, rounded to fit in wooden bearings, or it may be of wood, but with metal ends or bearings, or it may be gas-pipe shafting, or, as is not uncommon, the axis of a buggy or wagon. This is the fundamental part, and to it are attached the four fans, six fans, eight fans, or many fans, as the case may be. The jumbo itself can not exceed the battle-ax in simplicity, cheapness, or power. The battle-ax mill is presumably the superior of the jumbo in all respects. These are mills of simple, cheap, and easy construction, and are efficient. In size they run from 8 to 10 feet, the more common sizes, up to powerful mills 16 feet in diameter.

Grand Island, in the Platte Valley, about 90 miles west of Lincoln, is a center for windmills. They are found in the town and for miles

around. Irrigation in this portion of the State is not strictly necessary. It is simply a way of increasing the ordinary quantity or quality of the yield, and is resorted to sparingly. Some of these mills were so nearly indistinguishable from the shopmade mills that they need not be reproduced. The majority are of the battle-ax type, and are especially commended to the attention of farmers and stockmen.

The four-blade battle-ax, about 8 feet in diameter, is the favorite type around Grand Island and farther west. Such a mill, with pumping capacity sufficient for 100 to 125 head of cattle, may cost $2 or $3, but should not cost $10, and may be built by those who are inventive without any outlay. Poles and strong limbs answer the purpose as

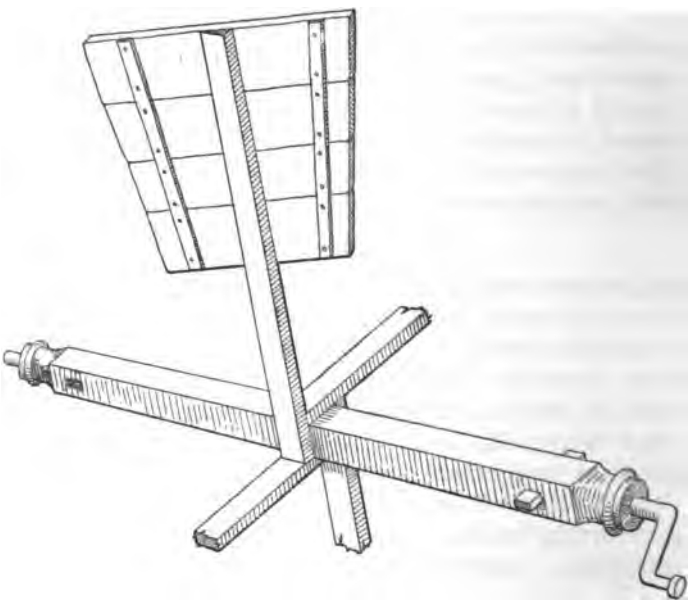
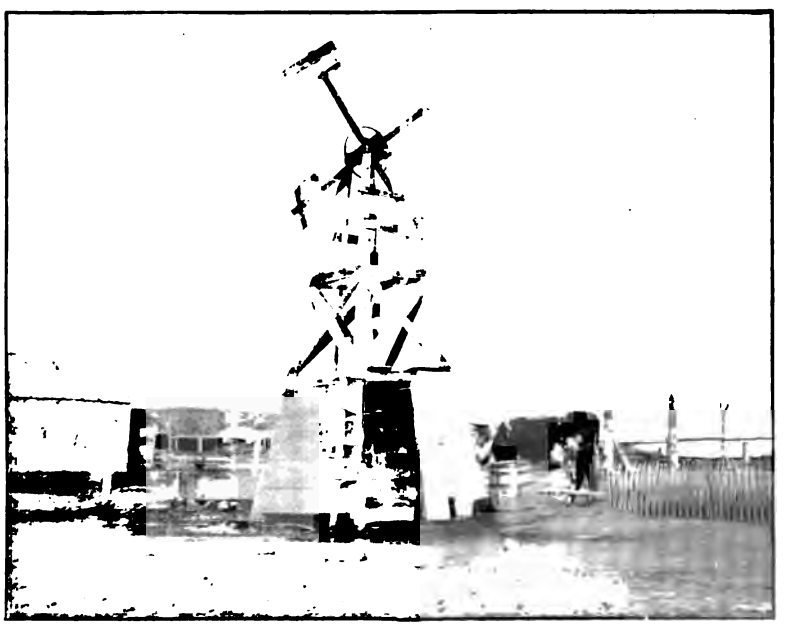


FIG. 11.—Details of construction of battle-ax windmills, showing axis 8 feet long, 6 or 8 inches square, iron bearings, arms 6 feet long, fans about 3 feet square, made of thin lumber.

well as new lumber, old dry-goods boxes furnish material suitable for fans, and old wire, nails, and bolts are common on every farm. The majority of the mills are made in this way, although some are much more elaborate. The principle of the adaptation of discarded machinery is particularly exemplified in the construction of the battle-ax mills. In most of them the journals, gearings, rods, springs, wheels, nuts, bolts, braces, and lumber of discarded machinery are used. Accordingly they are provided with well-made and fairly frictionless bearings, which help to render them sensitive to light winds.

The mill of Mr. Jacob Geiss, near Grand Island, which may be regarded as typical, is a 12-foot four-fan battle-ax, with an axis 8 feet long, mounted upon a suitable tower. It pumps from a shallow well more than is required for 125 head of cattle. (See fig. 11.)

A. BATTLE-AX WINDMILL ON FARM OF MATTHEW WILSON, NEAR OVERTON, NEBRASKA.



B. BATTLE-AX WINDMILL ON FARM OF FRED WOULF, NEAR GRAND ISLAND, NEBRASKA.

From Grand Island westward to Ogallala the battle-ax is the dominant type of homemade mill. At Overton, on the farm of Mr. Matthew Wilson (Pl. XV, *A*), are found two battle-ax windmills, each on a quarter section of a beautiful and improved farm of 1,600 acres, and each pumping water for 50 head of cattle. This is a large farm, and with several hundred head of cattle, as many hogs, and a barn full of milch cows and horses, it was found convenient to supplement the work of two large Perkins mills with two battle-ax mills. The two

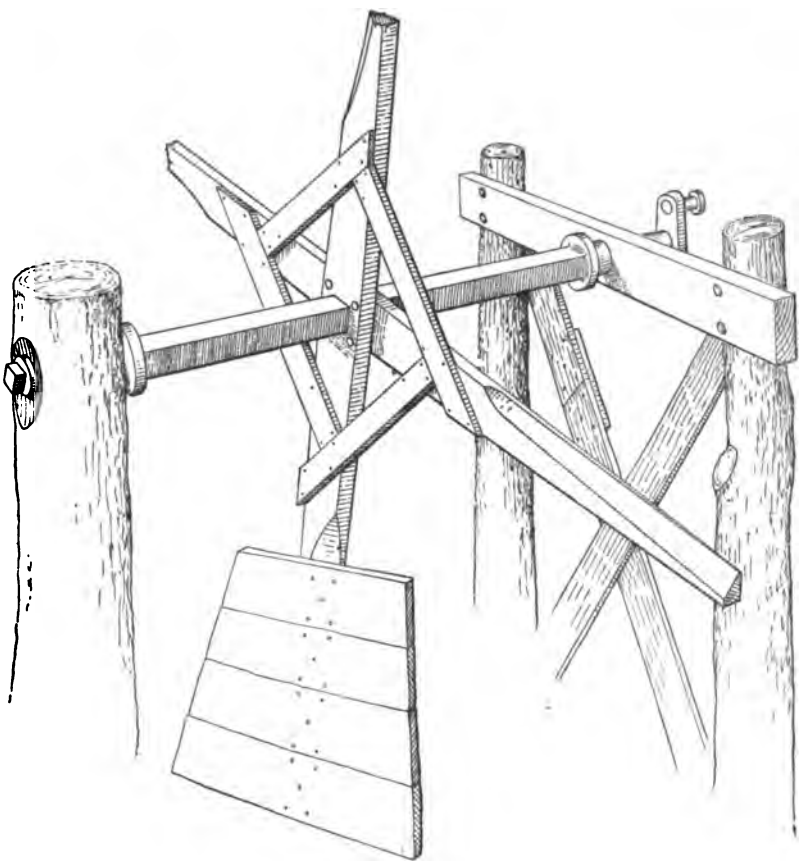


FIG. 12.—Working parts of a four-fan battle-ax windmill on the farm of Matthew Wilson, Overton, Nebraska.

latter were built at a cost of $1.50 each, and each pumps for its quarter section. In addition, one pump irrigates successfully 1 acre of garden, the water being conducted from the pump to the rows by 1-inch galvanized-iron pipe. Nowhere is there a more intelligent use of material. Three cottonwood poles, as shown in fig. 12, properly anchored and braced, constitute the tripodal tower, a buggy axle and thimbles the axis, and thin lumber the fans. In these bearings—kept

well oiled—the mill runs as smoothly as formerly did the carriage wheel on its spindle. The crank is adjustable to an 8-inch or 5-inch stroke, as desired. (See Pl. XV, *A*.) In Pl. XV, *B*, is shown the battle-ax wind-mill, tower, milk-house, and stock troughs of Fred Woulf, near Grand Island, Nebraska. The diameter of the wheel is 10 feet, and the cost $3 to $5. This mill pumps water for 48 head of cattle. The method of construction is shown in fig. 13. To stop the mill the rope attached to the long crank is made fast to a cleat at the base of the tower.

Six- and eight-fan battle-axes differ from four-fan mills chiefly in numbers. However, they are usually considerably larger and variously modified, and worthy of special mention, at least in several instances.

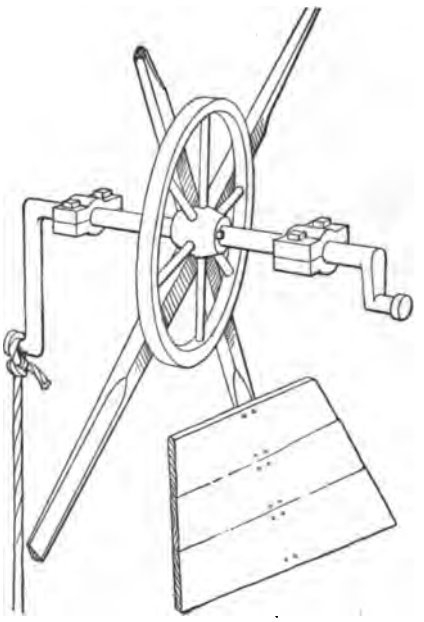


FIG. 13.—Method of construction of the battle-ax windmill of Fred Woulf, near Grand Island, Nebraska. Brake rope and crank to the left.

The six-fan battle-ax windmill of John Harders, near Grand Island, Nebraska (see Pl. XVI, *A*), is 8 feet in diameter, and cost, including tower, pump, and pipe, $12 to $14. It is used for irrigating a small market garden, and is mounted on a firm tower of cottonwood poles, broad at the base. The brake, managed by the brake rope, rubs against a cogwheel keyed to the axle, and thus controls the wheel.

The eight-fan battle-ax windmill of Mr. Diedtrich Huennecke (Pl. XVI, *B*), near Grand Island, attracts special attention, because it is made of old material, at a cost of but $14, including the mill and an unusually large and well-ironed water tank. The mill alone cost $6 to $8, and in efficiency is a rival of the steel mill costing ten or twelve times as much. The diameter of the wheel is 10 feet, and the stroke 8 inches. The mill was located in the stock yards, bordered by stalls and pens, and pumped from a shallow well all of the water needed by the stock. It was supported by heavy cottonwood posts, on which was bolted the framework from a thrashing machine, with journals and cogs in place. The cogs were geared in the ratio of 3 to 1. The fans, which are 3 feet long, 14 inches wide below and 20 inches wide above, were made of the sides and ends of boxes. Advantage was taken of the fact that an old pulley was attached to the shaft (fig. 14). A friction brake, managed

A. SIX-FAN BATTLE-AX WINDMILL OF JOHN HARDERS, NEAR GRAND ISLAND, NEBRASKA.

B. EIGHT-FAN BATTLE-AX WINDMILL OF DIEDTRICH HUENNECKE, NEAR GRAND ISLAND, NEBRASKA.

by an old wagon brake, was cramped on the pulley, checking or stopping the mill.

The largest and most remarkable battle-ax mills in the State are probably those of J. S. Peckham, 5 miles southwest of Gothenburg, and of his son, E. L. Peckham, a mile distant.

These are veritable wind engines, and they probably illustrate what may be done by the homemade mill better than any of the other mills visited. On this splendid farm, of a thousand or more acres, there is an interesting array of windmills, houses, barns, grain houses, sheds, cattle yards, orchards, vineyards, and the young but lofty trees of a timber claim. There were four shopmade mills, one Dempster, two Perkins, and one Aermotor, pumping water for the stock and for the

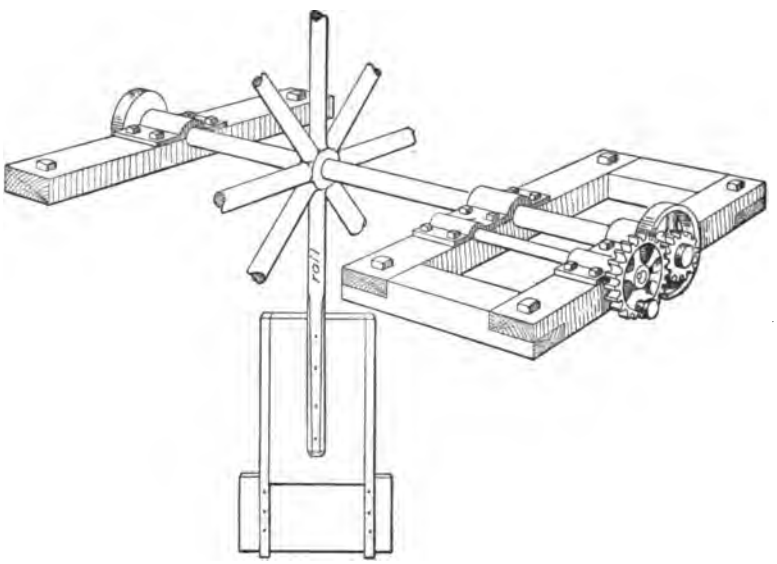


FIG. 14.—Working parts of the eight-fan battle-ax windmill of Diedtrich Huennecke, near Grand Island, Nebraska, with one fan in position.

house, and two giant battle-ax mills, driving two pumps each for the irrigation of 15 acres of orchard, vineyard, and small fruit.

These mills were designated Mill No. 1 and Mill No. 2, shown on the left and right, respectively, of Pl. XVII, *A*. Both were mounted on the same kind of tower, and were identical in size and make. No. 1, however, worked two pumps with 3¼-inch cylinders, and No. 2, two pumps with 4-inch cylinders, so that the results, as shown by the amount of water discharged, were quite different.

The towers, each about 20 feet in height, were made of timbers 2 by 4 inches with pieces 4 by 4 inches for the corners. They were broad at the base, about 16 feet square, and well cross-braced. The wheel,

16 feet in diameter, consisted of eight heavy wooden fans 5½ feet long and 5 feet at the top, tapering to 2½ feet below (about 25 square feet of surface on each fan). These were cross-cleated and very rigidly made and then securely bolted on a slant to the double 2 by 4 inch arms. The arms were made by springing and bolting into position pairs of 16 feet 2 by 4 inch timbers over the axis, which was 8 inches square, and had a span of 16 feet. The axis was not solid, but consisted of

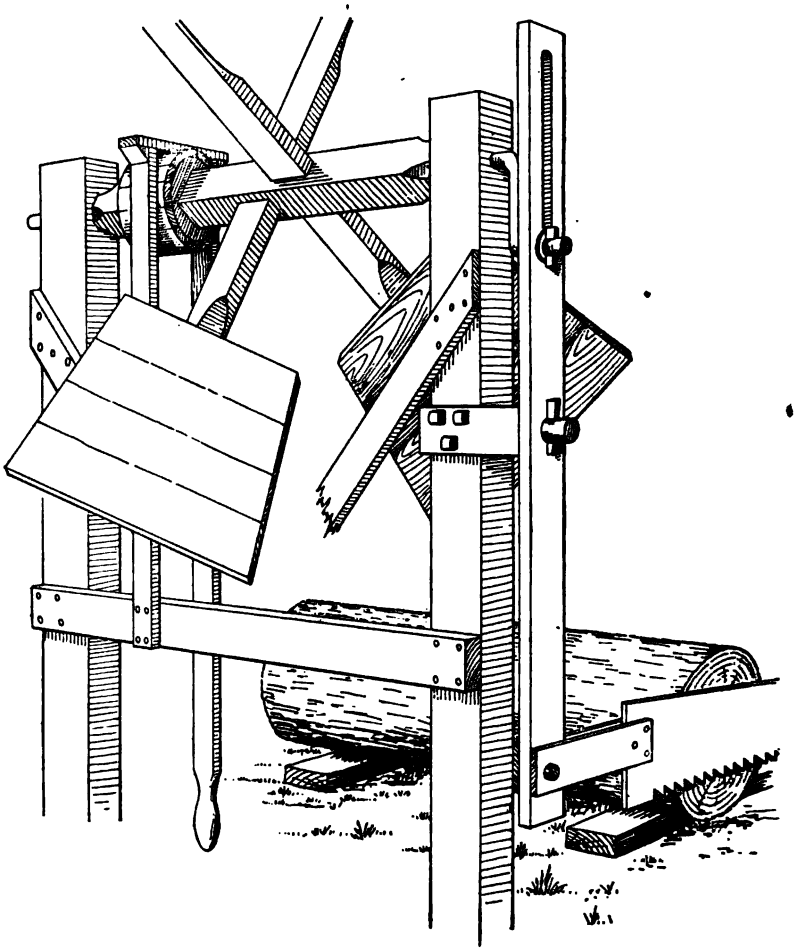


FIG. 15.—Battle-ax windmill driving crosscut saw, built by A. G. Tingley, Verdon, Nebraska.

two planks 4 by 8 by 16 feet, spiked and bolted together. This offered an advantage in the judgment of the designer, in that it allowed the adjustment and keying in place of the 2-inch iron bearings which carried the cranks and on which the axis was to turn. Their size demanded special rigidity, which the designer did not overlook at any point. They were admirably constructed, and ran as smoothly and as noiselessly as a steel mill. They cost about $25 each (exclusive

A. GIANT BATTLE-AX WINDMILLS ON FARM OF J. S. PECKHAM, NEAR GOTHENBURG, NEBRASKA.

B. TWO-FAN BATTLE-AX WINDMILL BUILT BY ELMER JASPERSON, ASHLAND, NEBRASKA.

of labor) and partly irrigated 15 acres of orchard, which they are capable of irrigating well when the water is economically and properly applied.

As to efficiency, Mill No. 1, with two 3-inch cylinders and a 10-inch stroke, pumped in a 13.5-mile wind at the measured rate of 14,760 gallons in twenty-four hours from a well 42 feet deep, although one valve was badly out of order.

Mill No. 2 made a better record, both because of the larger cylinders and the better condition of the valves. In a 13.5-mile wind this mill, with a 10-inch stroke, discharged at the rate of nearly 1,000 gallons per hour (or to be exact 930 gallons per hour), or 22,320 gallons in twenty-four hours, from a well 42 feet deep. This amount was greatly exceeded when, later in the day, the wind velocity rose to 15 miles per hour. Though not apparently overloaded, Mill No. 2 ran appreciably slower than No. 1.

From the farmer's standpoint, mills capable of doing such work can not be purchased at a price commensurate with the cost of building them. Thus some have built mills who otherwise would have bought them. These two mills are a credit to any estate, and are commended by the author to the consideration of farmers who prefer to build their windmills for heavy service.

A mile distant is the farm of the son, E. L. Peckham, who owns property almost as extensive as that of the father. The farmhouse looks like a city residence, with its fine green lawn. The young orchard, large vegetable garden, and flower garden, 2 acres in all, are models, due to the water supplied by a mill exactly similar in all respects to the original battle-ax mills Nos. 1 and 2, except that this is more heavily braced and otherwise improved. It lifts water 27 feet by two pumps with 4-inch cylinders, irrigates 2 acres, and sprinkles the lawn. The total cost, including pumps and all incidentals, was $75.

The remarkable two-fan battle-ax mill of Elmer Jasperson may be seen near Ashland, Nebraska, mounted along the ridge pole of a north-south corncrib and wagon house (see Pl. XVII, *B*). Heavy semicircular fans of wood, with a diameter of 10 feet, are mounted on a substantial axis having a span of 12 feet; to this is attached the sprocket wheel and chain for transmitting the energy of the wind to the corn sheller and feed grinder below. These fans are movable, and when brought together form a circle 10 feet in diameter, with its edge to the wind, in which position the fans are not affected by the wind, and are accordingly out of gear; but when thrown aslant the wind strikes their oblique faces, and they revolve with a fine display of force.

This mill is not so sensitive to light winds as shopmade mills, but its momentum is greater. It drives a two-hole cornsheller and feed grinder and a grindstone.

This is one of the most interesting and attractive homemade designs in the State, and for novelty and originality it was awarded a prize by

the Nebraska State Journal of Lincoln. It shells and grinds corn at a total outlay of $11, and gives entire satisfaction. The ingenuity which characterizes this novel invention crops out everywhere on the Jasperson farm, in the locks, gates, fences, and implements, and in one irrigated field there is a remodeled turbine, described on page 65, so well made as to be indistinguishable from the original mill.

Regular shopmade mills supplied water for his house and stock, the homemade mill being used wholly for driving machinery. Unfortunately means were not at hand for measuring the true efficiency of this two-fan turbine, but for practical purposes it may be said that it drove the cornsheller and feed grinder with ease. It seemed equivalent to about 1 horsepower.

HOLLAND WINDMILLS.

The Holland mills, with their four slatted fans covered with cloth sails, are so familiar in art that descriptions are unnecessary. However, as introduced into the Great Plains, they have undergone many changes and modifications, and the resemblance is sometimes lost. As viewed in pictures, the great fans are mounted on massive supports. In Nebraska, however, they sometimes stand on slender, spindling towers. They are frequently mounted upon milk houses, corncribs, wagon sheds, and barns. Their identity is further obscured at times in that the customary four fans are replaced by six or eight, and the familiar duck sails by wooden ones.

Some of the strongest and best mills in the State are modifications of these old Dutch mills. Though the picturesque mountings and settings may be wanting, their efficiency and serviceability are not. The smaller Dutch mills stand on towers, the medium-sized on small outbuildings, and the large ones on barns. In size they range from the smallest, 10 to 12 feet in diameter, through medium-sized mills, 15 to 20 feet in diameter, to the largest, which measure 36 feet.

The great Holland mill of August Prinz, 1 mile east of Chalco, Sarpy County, favorably situated as it is for observation from passing trains on the Burlington Route, has become a familiar landmark to travelers on that road (see Pl. XVIII, *A*).

The Prinz mill rises high above the surrounding grove, which, though but twelve to fourteen years old, completely shuts in the house and farm buildings. A closer view shows the large mill, with fans describing a circle 36 feet in diameter, mounted securely upon the large shed which constitutes corncribs and wagon shed, while at the house is seen an 8-foot Gem mill which pumps water from a 40-foot well to the house and stock trough. As a precaution against accident and against insufficient wind velocity, the owner has a horsepower device with shafting and pulley, which can instantly be attached to the house pump.

Ordinarily the small windmill is able to supply ample water for the

A. HOLLAND OR DUTCH WINDMILL OF AUGUST PRINZ, NEAR CHALCO, NEBRASKA.

B. SIX-FAN HOLLAND OR DUTCH WINDMILL OF HENRY BORMANN, NEAR PORTAL, NEBRASKA.

house, for 80 steers, 20 milch cows, 10 horses, 125 hogs, and other stock. Accordingly the large mill has so far been employed solely for the purpose of grinding grain, although it can be easily geared to raise water as needed. In the amount of grist is found an easy measure of the efficiency of this mill, which owes much of its merit to the fact that its projector had built mills in Holland before emigrating to this country in 1871.

With the ordinary wind of winter, when the mill is particularly in use, the capacity of this mill is 200 or even 300 bushels of ground grain a day. It drives an 8-horsepower feed grinder with greater speed than horses could. It elevates the grain and grinds and discharges the grist automatically, demanding no immediate supervision, while the men are engaged about the customary duties of the farm. With a good wind it is unnecessary to use more than two sails, which give all the power that is necessary for ordinary work.

This being a large mill, heavy gear wheels and driving wheels, couplings, brakes, etc., were necessary, and these were procured in Omaha and Chicago. The total cost of the mill was $150. While this may appear to prospective builders a considerable sum, it is not prohibitive. Against this sum must be balanced the efficiency of an 8-horsepower plant, the fact that the mill requires little or no superintendence, and that the grain is ground at home, requiring no expenditure of time and money in hauling to and from the mill. A windmill so well built is capable of rendering service for twelve to fifteen years.

Here, as elsewhere, the author finds that those farmers who have the ingenuity to invent and build mills have well-kept farms, the best gates and fences, improved and excellently kept buildings, and an air of unmistakable prosperity. In twenty years the proprietor has become possessed of 320 acres of fine land set with hedges, groves, and orchards; of herds of well-bred stock and fowls; of substantial, convenient, and well-regulated houses, barns, cribs, tool sheds, and poultry houses, and of all necessary farming implements and vehicles. The author has driven for many miles through this favored agricultural region, and scarcely less can be said of any farm visited. They are large, well kept, improved, and free from mortgage. This is but the beginning of the great windmill area of the State, which extends thence westward for 500 miles in close proximity to the Platte Valley.

On the farm of Henry Bormann, near Portal, in Douglas County, about 3 miles east of the August Prinz place, stands an important mill of home production, which, like the Prinz mill, its progenitor, is a landmark familiar to travelers on that branch of the Burlington and Missouri River Railroad. It is essentially a Dutch mill, but with six instead of the customary four fans, which describe a circle 19½ feet in diameter. Making allowance for customary overestimates, its

true efficiency must be between 4 and 6 horsepower, and will run higher when the mill is full rigged. The surprising part is that it runs the grinder without full-sized canvas sails, its designer and builder finding that it was easier, handier, and amply efficient to use wind boards instead. These wind boards are simply thin ¼-inch boards about 7 feet long and 1 foot wide, set at an angle on each arm. They are quickly set in place and secured by wooden buttons. In a strong wind but three of these boards are used.

The capacity of this mill varies according to the wind, from 75 to 100 bushels of ground feed a day. By purchasing shafting, belts, pulleys, bevel gear, etc., at an abandoned elevator, and by making patterns for the revolving head and other parts and having them cast in Omaha, the cost of this mill amounted in all to only $50. Considering that it is well built, that it should last ten to twelve years, that it grinds all the grain for the stock and is capable of pumping and driving other machinery, there is again a decided balance in favor of the homemade mill.

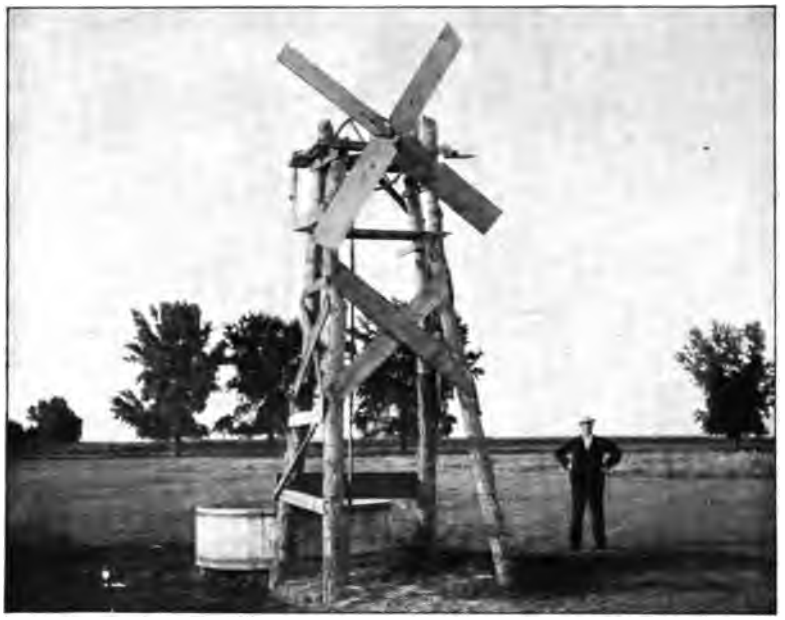
During the summer months when the cattle are at pasture the mill is not in operation, so that the author made no attempt to test its efficiency, believing that the 6-horsepower grinder was a sufficient measure of its strength. This, like the Prinz mill, is so geared as to be useful in driving other machinery or in pumping water, as occasion demands.

TOWERLESS TURBINES.

It is doubtful if there is a better general example of the towerless turbines than the one across the Platte, some 20 miles south of Gothenberg. This simplified mill consists merely of a wheel without tower, axis, crank, or other working parts. The axle of an old wagon, with spindle, thimble, hub, and wheel intact, was bolted to beams on the south side of a barn, fans were nailed at a slant to the spokes, and a bolt was driven in one edge of the hub with an eccentricity of 3 or 4 inches, to which the pump rod was attached. The mill pumps water, but is dependent, of course, on south winds. From this simple form there is every conceivable gradation to the best shopmade steel mill, made of the finest material, and wrought with such nicety and precision as to return 90 per cent efficiency.

STATIONARY TURBINES.

The next higher type of the turbine is but little more specialized. It has a tower, usually of poles, a crank and pump rod, and four or more blades or fans. These constitute the whole of a mill which is considerably more efficient than the extreme simplicity of its working parts might imply. These are commonly built without expense, for the crank, which is the only piece demanding outlay, is inexpensive if bought first hand, and is usually supplied from old machinery; and



A FOUR-FAN STATIONARY TURBINE WINDMILL OF FRIEDERICH ERNSTMEYER, NEAR GRAND ISLAND, NEBRASKA.

B SIX-FAN STATIONARY TURBINE OF FRED MATHIESEN, NEAR GRAND ISLAND, NEBRASKA.

to the crank arms are attached to which the wooden blades are nailed. The pump rod is often but a sapling. The axis runs on wooden bearings, lubricated occasionally with axle grease. The tower is built of old lumber, usually of poles. Such mills are numerous. Occasionally these mills run on excellent bearings, the builder having detached certain framework with its journals and crank from old machinery, bolting them bodily to the tower, attaching arms to the axis, a pump rod to the crank, and once in a while a brake to regulate the speed of the fans.

A mill of this kind (see Pl. XIX, *A*) used by Friedrich Ernstmeyer, of Grand Island, for pumping water for his stock, was especially well built, and cost only 32 cents—for a 16-foot board for the fans. It was made of the oak frame and sickle driver of an old mower, which was bolted bodily upon the cottonwood tower. This is an 8-foot wheel, with pine board fans 12 to 14 inches wide by 4 feet long. An ingenious brake was made by securely wedging an old cultivator wheel to the axis, and a set of springs and levers were so arranged as to press a shoe of leather against the wheel, thus retarding or stopping the mill as desired.

In the stock field of Fred Mathiesen is a six-fan set turbine (shown in Pl. XIX, *B*), which, though very crude and rustic, runs nicely in its shopmade bearings—the frame and journals of an old self-binder—and cost only a few cents, for welding an extension to the axis and for light rods with which to brace the arms. The brake is nothing more than a fence post, which can slide forward between the fans to stop them and back again to put the mill in gear. The pump rod is a small sapling. The diameter of the wheel is 8 feet and the stroke 6 inches; total cost two or three dollars. The turbine is used for watering stock.

From these elementary forms, which are too numerous to allow detailed description, we pass to the set turbine, with many fans. A typical example, selected from many, is the mill built by Janak Bros., of Sarpy Mills, Nebraska.

First attempts at designing and building mills often give results which warrant larger undertakings, and one may see the first, the second, and the third mill by the same designer, each an improvement on the one before. It is interesting to note this advance, which is marked by improved and enlarged designs and by superior material and make. An excellent example of this is furnished by the Janak Bros., the elder of whom arrived from Bohemia three years ago (in 1896). Seeing that it was important for a neighbor to supply, in a given pasture, water for about thirty head of cattle, he immediately built a turbine mill so simplified that it consisted merely of a 10-foot wheel made of weatherboarding, braced and wired together, mounted on an axis with a 3-inch crank, which ran in journals of wood, bolted to the top piece of the tower (see fig. 16). There was no need for a revolv-

ing head or vane, for this was a stationary turbine, with face set to the south, and with its tower well guyed in three directions by twisted wire. This mill cost altogether between $3 and $4, and at the worst is sure to give three or four years of satisfactory service, in addition to three years' service already rendered.

On the farm where poles may be cut for the tower and old lumber is at hand, the expense of a 10-foot stationary turbine mill like the above may easily fall within $2.50 or $3. These are commended to the attention of those needing cheap mills, especially to those who have material on hand. Here the crank and driving wheels of discarded reapers may be put to advantageous use.

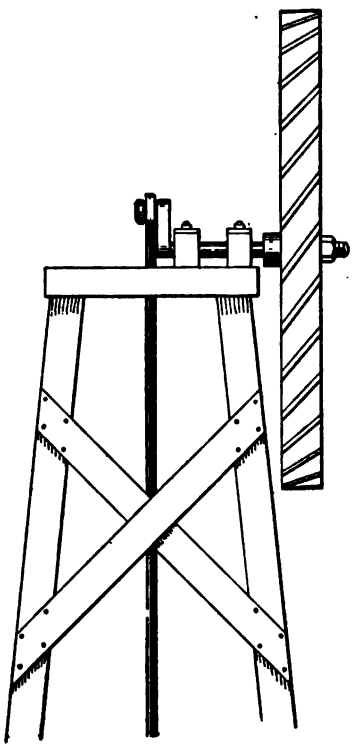
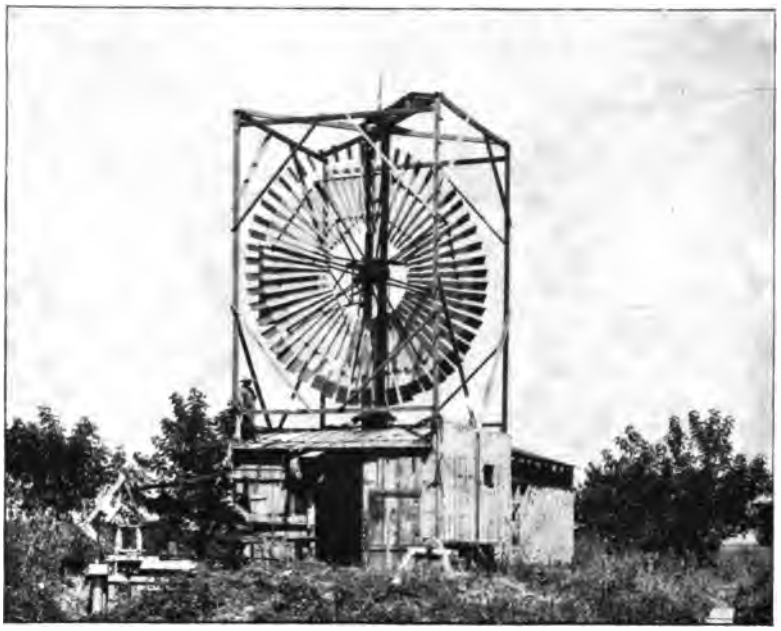


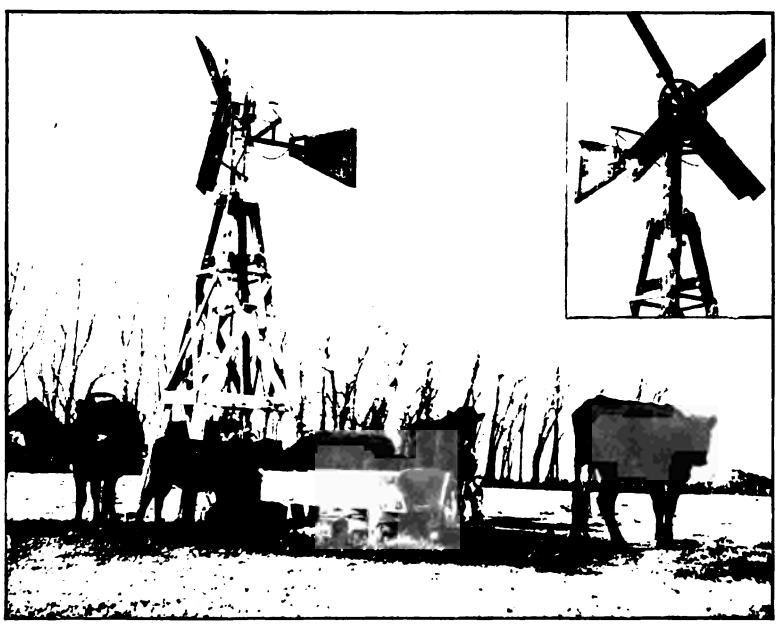
FIG. 16.—Stationary turbine designed and built by Janak Bros., Sarpy Mills, Nebraska.

This crude wooden mill warranted an attempt by the Janak Brothers at something larger, better built, and more complex in its parts. The result is a steel mill 14 feet in diameter, with galvanized-iron fans, mounted with a revolving head upon a 35-foot wooden tower by the side of the blacksmith shop of the Janak Bros. The finely built wheel was spinning without a sound or vibration, and within the shop the emery wheel, grindstone, drill, bellows, lathe, and other machinery, together with the pump, were driven as steadily as though steam was the motive power.

Their prestige as blacksmiths was won largely by the windmill, which not only drove their machinery, but evidenced their ability. This mill, well as it worked, was yet incomplete, a fortunate circumstance, as it illustrates the fact that in a great deal of machinery refinements and accessories are not essentials. The mill lacked a rudder or vane, which necessitated climbing the tower and prying the wheel face to the wind with a lever. This, however, in a region where the prevailing wind is so constantly from the south, occasioned but little inconvenience. At the same time this shows the prospective builder that he can simplify the working parts of his mill and reduce its cost without materially affecting its efficiency. Later on, as time and means allow, vane, automatic regulators, and other parts may be added at will. In the meantime the owner has the use of an efficient mill in which but little cash or time is invested, and though less



A. GIANT TURBINE BUILT BY J. M. WARNER, NEAR OVERTON, NEBRASKA.



B. FOUR-FAN GEARED TURBINE BUILT BY HENRY BOERSEN, NEAR GRAND ISLAND, NEBRASKA.

convenient it seems far wiser to have a mill like this than to be driven from the undertaking by its complexity.

VANELESS AUTOMATIC TURBINES.

The vaneless automatic homemade windmill of W. F. Baldwin, of Ainsworth, Nebraska, when visited September 12, 1898, proved to be

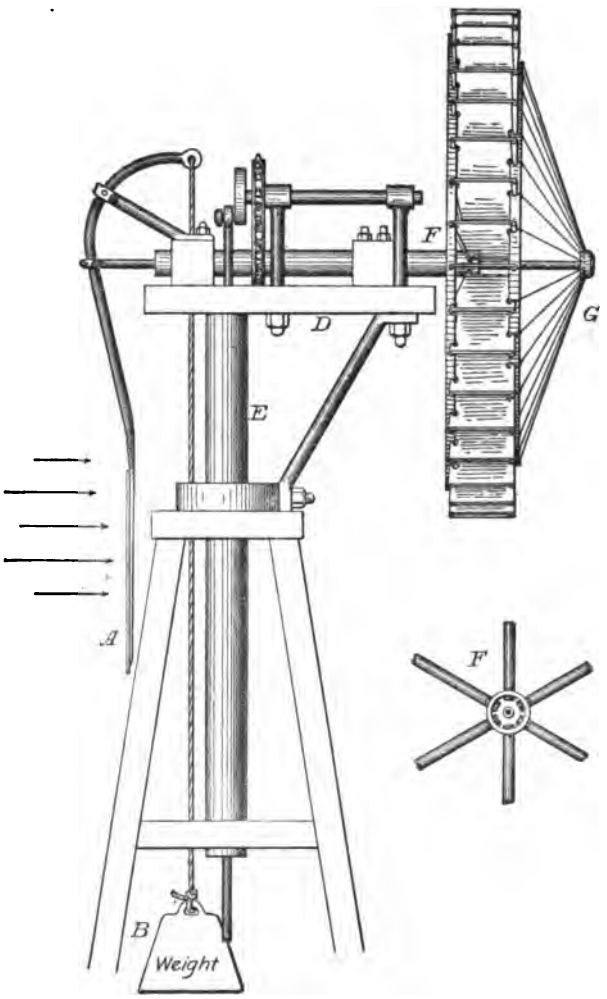


FIG. 17.—Sketch of homemade steel turbine of W. F. Baldwin, Ainsworth, Nebraska. *A*, Regulating fan and lever; *B*, Weight holding the mill in gear; *D*, Platform revolving about gas-pipe axis *E*; *F*, Windmill head with gas-pipe arms.

one of unusual interest (see fig. 17). A principle seems to appear in this mill not thus far seen in other mills.

Mr. Baldwin, who had formerly been engaged in several windmill companies, and had thus acquired experience, considered it a piece of faulty construction that shopmade mills must be subjected to the

fury of the wind before they begin to throw themselves out of action. This is a heavy and apparently an unnecessary strain, and to obviate it Mr. Baldwin so arranged his mill that the regulator receives the force of the wind before the fans. The regulating rudder (see fig. 17, *A*) is counterbalanced by a paint keg filled with sand; the rudder, thus becoming sensitive, reacts and responds to every varying breeze, constantly throwing the fans in and out of the wind. When the keg is removed the lever, falling of its own weight, pushes against a rod passing through the hollow axis, and thus sets each fan in the wheel edgewise, catching no wind. When the weight is applied each fan is thereby set to catch the wind to the best advantage. Between these two points there is every gradation, the blades constantly turning and adjusting and accommodating themselves to every breeze. Nine mills of this kind have been built and set up on farms around Ainsworth, and their owners are enthusiastic in their praise.

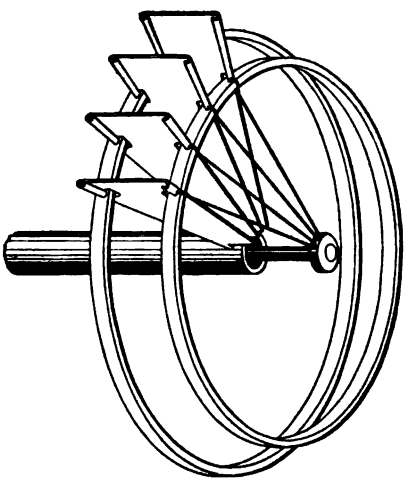


FIG. 18.—Method of regulating the fans of the homemade steel turbine of W. F. Baldwin.

The galvanized iron blades are reinforced with heavy wire on the edges, the back edges being hinged to a fixed metal circle, and the front edges to a slightly movable rotating one, which turns the fans according as the adjusting rod moves forward or back.

The working parts, consisting of a 2-inch gas-pipe axis to which the fans are attached, carrying sprocket wheels geared in the ratio of three revolutions to one stroke, were supported on a small platform, braced by rods, which revolved about a 3-inch gas pipe fixed in the tower. The tower consisted of staight cottonwood poles, bolted to anchor posts in the usual way. The axis runs on friction rollers, like the ordinary grindstone. By using pieces from old machinery the cost of this trial mill was but $5. It has been in service pumping water for the house and stock for three years.

GIANT TURBINES.

The giant turbine of J. M. Warner, 4½ miles southeast of Overton, Nebraska, is one of a size rendered possible by the method of mounting it inside the tower rather than upon it (Pl. XX, *A*). This arrangement so far extends the base of support that the tower can probably never be overturned, except by winds that would move buildings. In addition it is securely guyed in four directions by

A. RECONSTRUCTED WINDMILL OF E. M. SEARLES, JR., AT OGALLALA, NEBRASKA.

B. IRRIGATING POND AND RECONSTRUCTED WINDMILL ON FARM OF ELMER JASPERSON, NEAR ASHLAND, NEBRASKA.

heavy twisted wire, anchored at a distance. This giant turbine, which has no rival in size or strength, is an efficient innovation. It propels the machinery of a 4-horsepower feed grinder. However, the work is done with less dispatch than by four horses, and Mr.

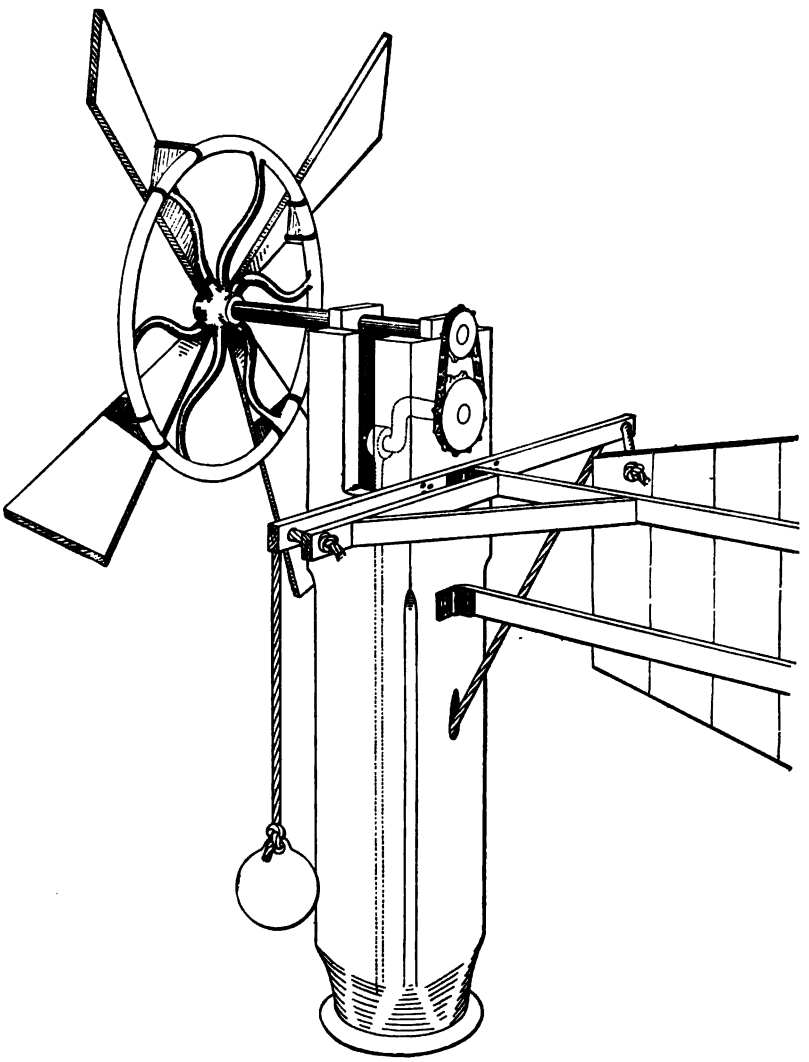


FIG. 19.—Method of construction of four-fan turbine mill of Henry Boersen, near Grand Island, Nebraska. General view on Pl. XX, *B*.

Warner is disposed to attribute to the mill an efficiency of 3 horsepower and possibly a fraction more.

In addition to grinding, this mill runs the grindstone and other machinery by means of a system of overhead shafting with pulleys and belts. It can also be connected to a walking beam, which drives

two pumps with a 12-inch stroke, one having a 5-inch cylinder, the other a 4-inch cylinder. These are too small for the mill, as Mr. Warner finds, and 6-inch cylinders should be substituted. The lift is but 7 to 8 feet, and the endless chain and buckets might replace the pumps with marked advantage. No reservoir has yet been built, but with one Mr. Warner estimates he could irrigate 20 acres sufficiently for that region. As it is, he has successfully irrigated 8 to 10

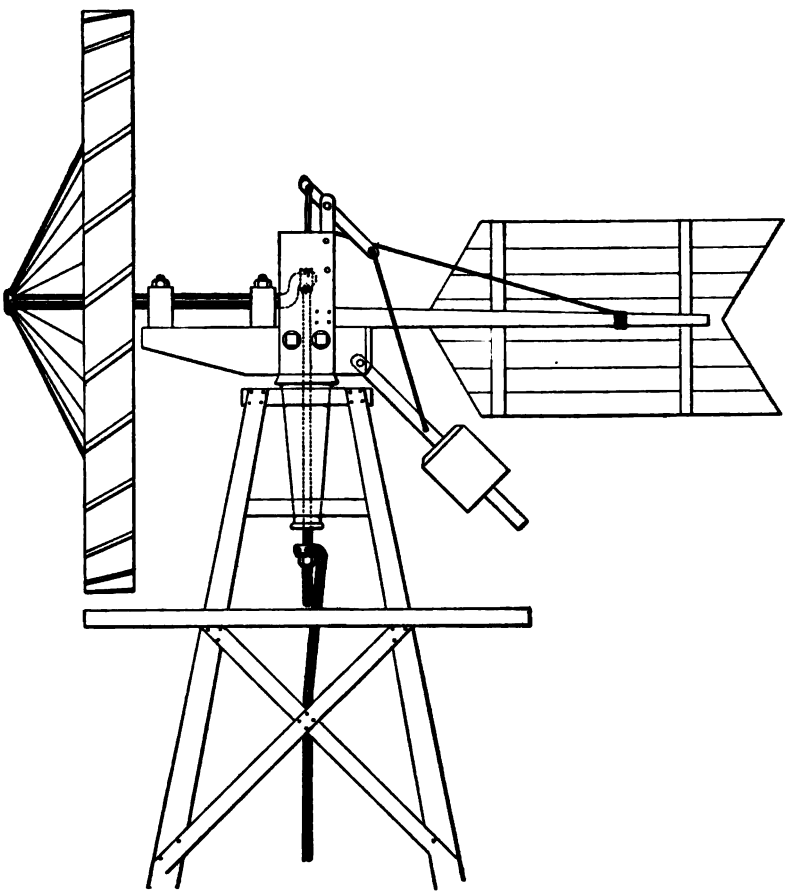


FIG. 20.—Homemade turbine mill of Lewis Jardee, of Newport, Nebraska.

acres of alfalfa and 6 to 8 acres of corn. The mill is large, and its cost, about $60, is not disproportionate to the work performed. A large rudder, held in place by a weighted nail keg, guides this giant wheel, which runs on a 2-inch iron axis, supported by a vertical rectangular frame. This principle is apparently new and worthy of development.

Plate XX, *B*, illustrates a four-fan geared turbine designed and built by Henry Boersen, near Grand Island, Nebraska. The head of

A RAILROAD WATER TANK AND WINDMILL.

B. ELEVATED TANKS FILLED BY WINDMILL FOR TOWN SUPPLY; USED AT FAIRMOUNT, FILLMORE COUNTY, NEBRASKA.

an old wooden pump constitutes the revolving parts, while the fly-wheel and sprocket wheels of an old cornsheller were used for the driving parts. But few bolts or screws were used, the parts being very ingeniously wired together. Examination of fig. 19 will make the working parts and plan of rudder apparent. The wheel is 8

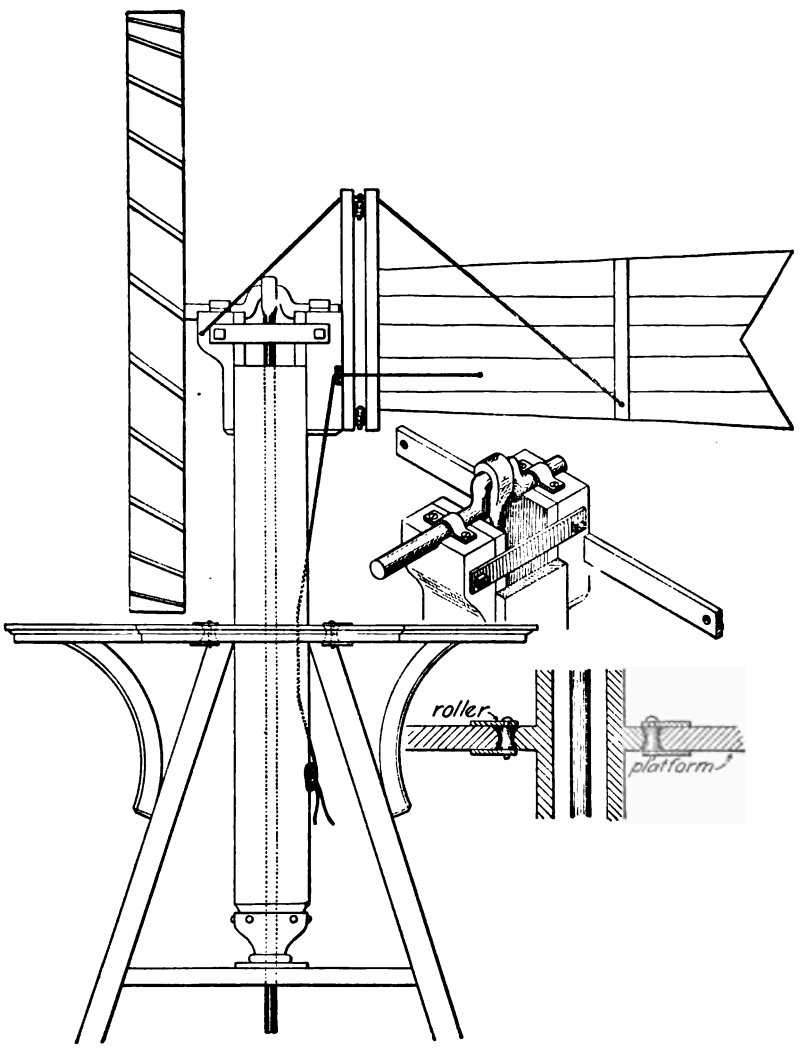


FIG. 21.—Side view and details of revolving parts of homemade turbine windmill of W. F. McComb, Grand Island, Nebraska.

feet in diameter; cost of mill, $2; cost of mill, pumps, and trough, $9.50. The pulleys over which the gear ropes pass are made of spools. This turbine raises water from a shallow valley well 7 or 8 feet and supplies 60 head of cattle. The timber shown in the background is 26 years old.

The homemade windmill of Lewis Pardee, Newport, Nebraska, shown in fig. 20, consists of the thimble of an old wagon—on which the mill turns—to which are bolted for the driving parts oak supports detached from an old reaper. The mill pumps about 500 gallons an hour, or 12,000 gallons in 24 hours, and cost $6.

Some homemade mills are such close imitations of the shopmade, that the casual observer fails to see the differences which are apparent on closer inspection.

The mill of W. F. McComb, of Grand Island, shown in fig. 21, is an example. In appearance it is a shopmade mill; in fact every portion of it is homemade. The fans are of metal, the rudder of light wood, hinged, and adjustable from the ground to throw it in and out of gear like ordinary mills. The mill acts directly on the piston, giving a 10-inch stroke. The head and axis are supported on a vertical wooden box, which, guided by friction rollers set in the platform of the tower, revolves upon a conical casting at its base. It is a 10-foot wheel, pumps water by a 3-inch cylinder into the tank, a lift of 44 feet, and irrigates the garden and lawn. It cost possibly $20, and has run since the spring of 1897.

RECONSTRUCTION OF WINDMILLS.

In the provisional classification of homemade windmills, the reconstructed mill is placed next in importance to the shopmade mill.

There are great possibilities here, which have been and may be taken advantage of many times. In every community are neglected or fallen mills and towers which might be reconstructed at a merely nominal cost, either by the owner or by the purchaser of such idle property. The essential parts are often intact, and it is a simple matter to substitute homemade fans and rudders for those missing. Many mills are standing in disuse year after year, while rough boards nailed to their bare arms would start them going.

Many take advantage of this opportunity, and that others may be reminded of the possibility a few reconstructed mills will be figured and described, in the belief that this small number will sufficiently represent all.

Reconstructed mills are to be found in every county in the State, but nowhere are there better examples than at Ogallala, in western Nebraska. Within the town at least five reconstructed mills are in use, pumping water mostly from shallow wells.

At the livery and feed stable an old mill which has lost all its fans and its rudder has been so rejuvenated by simply nailing 6-inch boards to the bare arms that the mill is pumping water for 25 horses. This entailed no expense and but little time and labor.

Near by stands a reconstructed mill still doing duty in pumping for the house and lawn, though furnished with six rough blades. The mill which formerly occupied its place upon the substantial tower had

ARTIFICIAL PONDS OF THE MOULTON ICE COMPANY, LINCOLN, NEBRASKA. SUPPLIED WITH WATER BY TWO TURBINE WINDMILLS.

been racked by gales and storms, and had been allowed to lose its woodwork and so fall naturally into disuse. However, the essential parts remained as a base, to which homemade parts could readily be attached without cost. (See Pl XXI, *A*.)

Within a few blocks is to be seen the most interesting one in the place. It stands on a slender steel tower, like a veritable toy mill, but it pumps water for the house, for four horses, and for the irrigation of the lawn and garden.

The success of this toy turbine is due in a measure to the fact that it is a reconstructed aermotor. Two sets of galvanized fans and rudders had been demolished, and the last time the iron fans were replaced by thin boards 5 inches wide and 2 feet long wired firmly to the six iron arms. The rudder was left off; accordingly, instead of standing face to the wind, it swings around automatically (because slightly eccentric) and stands back to the wind. Thus the motion is reversed, and the fans run backward, but with no apparent disadvantage.

On measuring the wind velocity with an anemometer, and measuring the water pumped, the following results were obtained: In a 15.5-mile wind this toy mill lifted from a shallow well (12 feet deep) a trifle more than 270 measured gallons in an hour, or at the rate of 6,500 gallons in twenty-four hours, its efficiency being one-eighth horsepower.

Near Kearney is a reconstructed mill whose arms have been slightly lengthened, and to their extremities were nailed light fans made by boys of the farm from the thin sides of boxes. Although this gave a rough and unnatural looking exterior, the small irrigating reservoir stood full of water. The admirably constructed mill of Elmer Jasperson near Ashland, Nebraska (shown in Pl. XXI, *B*), seems to differ in no respect from the best shopmade type, although it had been a total wreck. It was purchased for $3 as it lay on the ground twisted and broken, and hauled to the Jasperson place. At an additional outlay of $7 the bent parts were straightened, the tower rebuilt, and the mill reinstated as good as new, so far as outward appearance and action are concerned.

SHOPMADE TURBINES.

The highest type is the shopmade mill, which is so closely allied to every well-regulated Western home. These mills are inseparable features of every landscape, of every farm, village, and town. One may count as many as twenty-five or thirty mills in view at one time from the car window in passing, and thirty or forty in any town. These mills have given to the country home many of the comforts of the city. They enable small towns to have water systems with standpipes, water mains, and hydrants, a satisfactory domestic water service, and a supply with ample pressure for fire protection at a cost much below that for similar water service in a city.

The windmill and tank are the conspicuous and characteristic land-

marks of every siding and station in the prairie. (See Pl. XXII, *A*). Asylums, homes for soldiers, orphans, blind, and feeble minded, and other public institutions in rural districts isolated from city conveniences depend on the windmill. The town pump has given way to the town windmill and tank, which easily furnish water for the public watering trough and the public hydrant.

In villages too small to assume the expense of standpipe, water mains, and hydrants, pressure for fire protection is often obtained by carrying the tower of the public tank as high as need be, and mounting upon it a second tank for use in case of fire. (See Pl. XXII, *B*.) Precaution is generally taken to augment the mill with a good steam, gasoline, or petroleum engine for use in emergency, or in case of a continued calm. This makes an excellent and cheap system. The mill is the main dependence, the engine being pressed into service but occasionally.

In many towns and cities the turbine is used to pump water for fish ponds and ice ponds. In the smaller towns the irrigating pond of summer is turned to good account in winter, in furnishing an ice harvest. In Lincoln, the Moulton Ice Company harvests its ice from three artificial ponds supplied with water by two turbine mills. These same ponds are stocked with several thousand fish. (See Pl. XXIII.)

Under the refining influence of the windmill, the pioneer schoolhouse, first of sod, then of lumber, begins to lose some of its utter barrenness, and sod, trees, and shrubs begin to grow.

ORIGINAL USES FOR SHOPMADE WINDMILLS.

The shopmade mill is often harnessed to homemade water lifters of unique and original design. These are as interesting as the homemade mills themselves, and are worthy of a special report, which the author has in preparation.

One or two examples will illustrate this group sufficiently for the present.

At Milford, on the banks of Blue River, may be seen a large mill and tower (see Pl. XXIV), now in disuse, geared to run an endless chain of 34 buckets, each holding 4 gallons. This method of raising water is one of the oldest as well as one of the best. However, in this instance, the mill is so completely overtaxed as to be rendered useless. Smaller buckets and lighter machinery would doubtless give satisfactory results. The possibilities of this kind of irrigation are great, and every river bank shows some kind of an attempt to pour the water upon the land. Some of these water lifters are driven by the current, some by windmills, and some by horse power or steam power.

At North Platte the natural order of things seems somewhat reversed through the use of a tympanum wheel, run by a large aermotor, instead of by the current. (See fig. 22.) The tympanum is primarily

WINDMILL AND WATER ELEVATOR ON BLUE RIVER, NEAR MILFORD, NEBRASKA.

a current wheel, but in this case, there being no current, its place was supplied by a 12-foot aermotor, which caused the tympanum wheel to revolve once a minute in a good wind and to discharge at each revolution 8 barrels of water through the hollow axis, lifting it 7 feet and irrigating 60 acres. This tympanum is beautifully built and

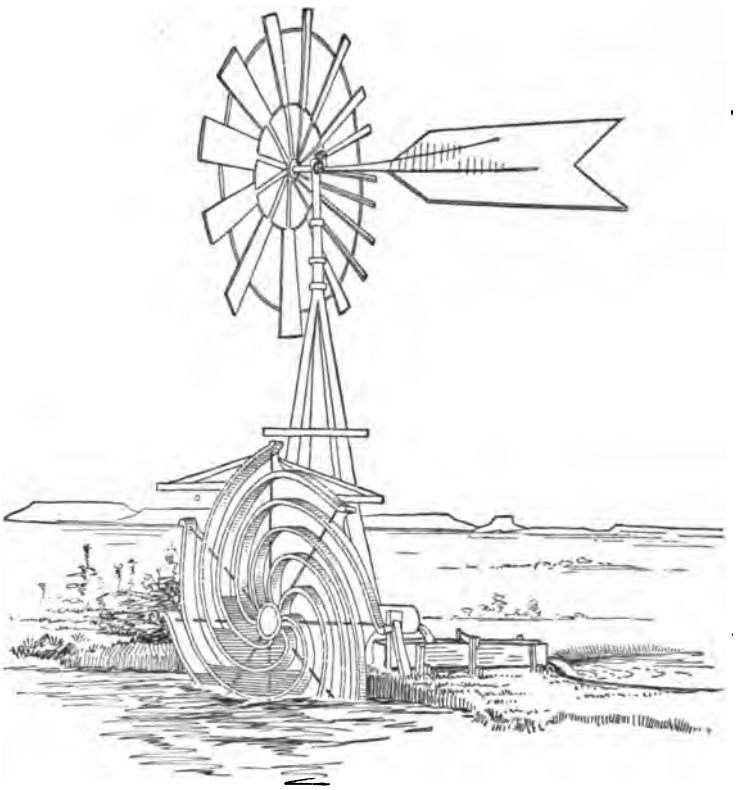


FIG. 22.—Two-foot tympanum water wheel operated by 12-foot aermotor; invented and built by David Thomas, of North Platte, Nebraska.

accurately constructed, but it is not at all unlikely that buckets or even pumps would give equal results at less expense. The cost was $100.

OTHER FORMS OF WATER LIFTERS.

Anticipating a future chapter on the water lifters of Nebraska, the author, knowing the demand for hints on all such matters, can not refrain at this point from mentioning some other water lifters, though foreign to the immediate subject. The principal water lifters other than the windlass, hand pump, windmill, horse-power, gasoline, petroleum, and steam engines are the endless chain and buckets, current wheels of all sizes and makes, Archimedes screws, jacketed screws running at high speed, etc.

The endless chain and bucket, of which there are many makes, is an

economic and successful water lifter, easily taken down and set up again, and not easily injured. For short lifts these seem worthy of first consideration.

The water elevator of John W. Karr, 1 mile southeast of Benkelman, Dundy County, is partly homemade and partly shopmade. Taking advantage of the failure of neighbors who had purchased a link-belt elevator at Chicago a few years before, he obtained the working parts for $5, and for about $2 in addition purchased lumber (2-inch plank) for the construction of the woodwork. A second-hand horsepower, with the necessary tumbling shaft, cost $13, and the mill was complete. Digging the well was a matter of a few hours with team and scraper, and the subsequent work was performed with the shovel. A total depth of about 12 to 14 feet was reached, the water standing 6 feet in the well. The well had a diameter of about 8 feet at the bottom, tapering to 5 feet above, tightly curbed with boards. The vertical lift was 7 to 8 feet, and two horses had about the same draft in elevating 27 cubic feet of water a minute as in plowing. The well discharges sand, pebbles, and water in a fitful stream. The sand is fine and works into and fills the well. Over 100 cubic feet of sand and coarse gravel were forced out last summer (1898), silting down the entrance of the irrigating ditch, which had to be dug over repeatedly. The sand here is fine and the delivery of water is too slow to supply the pump, but a few feet lower the gravel is coarse and the supply of water unlimited. This elevator will ultimately be attached to suitable windmill power, so as to use wind or horse power as occasion demands.

Mr. Karr irrigates about 2 acres of garden truck and 10 or 12 acres of alfalfa by contour ditches about 20 feet apart. Though the roots find ample water below, that portion of the field yielded best which was irrigated most, while the portions not irrigated at all were dead at least to the root. The mill has, as it stands—but not at its best—a capacity of 38,000 to 40,000 cubic feet a day according to the owner's measurements, and his claims were verified by the author as long as he watched its operations.

The lift here, which represents the conditions of the region, was scarcely more than 12 to 14 feet. Many failures in the matter of irrigating in this way result, as the author finds, from ignorance and bad management. Those who use intelligence and forethought are successful. Those who dig into fine sand, oblivious of the fact that it delivers water slowly, though the amount is unlimited, abandon the project without attempting to dig deeper or broader, or without tunneling so as to increase the surface for seepage. The fine sand also fills the well rapidly unless proper precaution is exercised. The result is that new elevators are soon for sale at second-hand price, and the man who is capable of maturing his plans gets the benefit of his neighbor's failure.

A. THIRTY-FOOT CURRENT WATER WHEEL ON BRANCH OF HAT CREEK, SIOUX COUNTY, NEBRASKA.

B. THIRTY-FIVE-FOOT CURRENT WATER WHEEL NEAR HOT SPRINGS, SOUTH DAKOTA.

A similar but larger water elevator is that of William James, near Crete, Nebraska. By purchasing Sieman & Schuske's buckets and chains and adapting them to his own power he has a water elevator capable of discharging 2,000 gallons a minute, the lift being 26 feet. Horse power and steam power are used according to the amount of water needed.

Mr. James first began to irrigate by hauling water from the creek and sprinkling it on the land. Finding this work slow and laborious, he built the elevator and soon had 50 acres successfully under ditch. Mr. James at the Nebraska State Fair of 1896 obtained second place for Saline County and received cash prizes to the amount of $300 and other awards to the value of $200.

Wherever there are live streams with good currents the current wheel is very common. Though changed and modified in many ways, the general plan is the same. The force of the current causes the wheel to turn, and in so doing a certain amount of water is caught in boxes or receptacles, carried to the top, and then discharged into a trough. Boxes, paint kegs, barrels, etc., are sometimes pressed into service and attached to the wheel in place of buckets.

The current wheel designed and built by David Hunter near Sutherland, Lincoln County, consists of eight swinging troughs each of 4 gallons' capacity hung to the eight paddles. These are emptied in succession as they come to the top. The cost of construction was $100. Large current wheels are capable of doing extensive work, and are engines of economic importance.

In Sioux County, on a branch of Hat Creek, may be seen a well-built current wheel (shown in Pl. XXV, *A*) 30 feet in diameter and capable of irrigating 15 to 20 acres, and farther north, at Hot Springs, South Dakota, may be seen a magnificent current wheel (shown in Pl. XXV, *B*) 35 feet in diameter, which is said to yield to its owner a cash money rental of several thousand dollars annually. In the figure showing this stately wheel the stream, which is small, though swift, is concealed by the rank growth of weeds and brush.

TRANSMISSION AND STORAGE OF WINDMILL POWER.

It is often found desirable to transmit the energy of the windmill to some other point, perhaps to the milk house or to the barn, in which case the mill, while pumping for the house or barn, may also drive one or more pumps at other points. When the distance is but a few feet the walking beam or the rocker shaft or similar devices are used, but the distance may be too great. The energy of the mill is often transmitted from one field to another, sometimes over hills and down draws. In such cases the energy is transmitted by strong wires attached to wooden quadrants or angle blocks. Though crude, they do good work and are practically as useful as the angle irons. It

seems better economy for the busy and well-to-do farmer to purchase these quadrants outright from his nearest windmill house, but for those who can better afford to spend energy and time than money the wooden angle block (see fig. 23) will prove an acceptable substitute for a better article.

If some of the surplus energy of the wind during certain seasons or during the more windy hours of the day could be conserved, it would apparently equalize matters to that extent. The best means to that end at present is literally to bottle it. That is, the windmill must compress the air into stout iron cylinders, or bottles, to be drawn

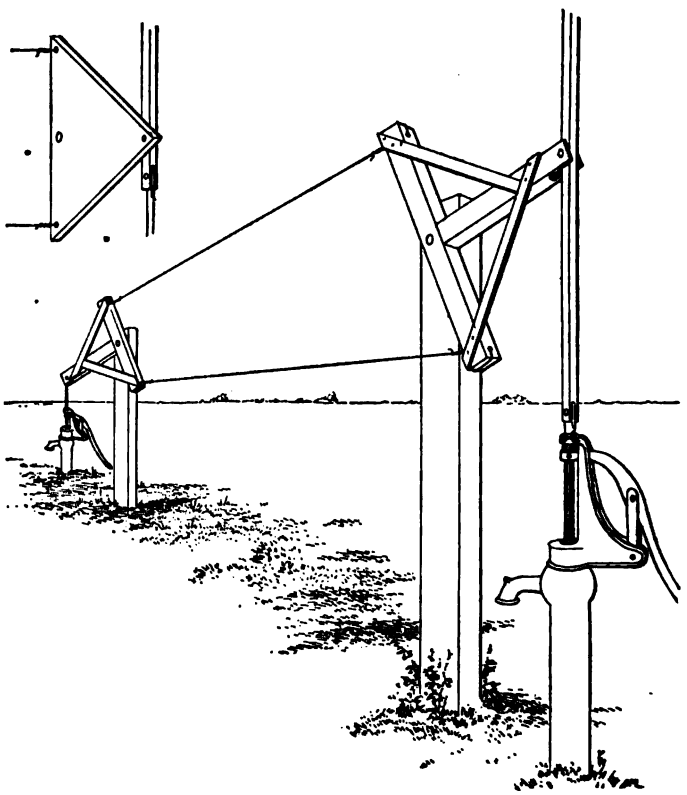


FIG. 23.—Transmission of power of windmill by oscillating wires.

off and used in any way desired. A small stream of compressed air admitted at the bottom of a tubular well often causes the water to flow as if it were an artesian well.

In many of our artesian regions there are countless spots in which water rises under pressure—and in that sense is artesian—but still does not flow over the surface. Such wells, treated to a small stream of compressed air, would flow vigorously like small "spouters." So far as can be learned nothing of this sort has yet been attempted in Nebraska, although it is contemplated. The park board of Omaha

has long considered this as a means of converting certain negative artesian wells into positive ones for the improvement of the park system of the city. In the Great Plains, where there is so much energy stored in the winds, a great natural resource seems to be going to waste for lack of development. It may be conserved by using the windmill to charge storage batteries.

PRECIPITATION IN NEBRASKA.

The climate of Nebraska is characterized by a low percentage of cloudiness, by a correspondingly large amount of sunshine, and by a dry and healthful atmosphere, whose chill in winter is less severe and whose heat in summer is less oppressive because of the low humidity.

Situated far inland, there are no great bodies of water to furnish evaporation. Little moisture finds its way from the Pacific slope, because of the Rocky Mountains. The rain-bearing winds come from the southeast, and the ultimate source of precipitation in Nebraska is the Gulf of Mexico. Although rainfall is rather limited, there is compensation in the fact that it comes at the season when crops are growing, and also in the fact that so great a proportion is absorbed and retained in the soil.

Professors Swezey and Loveland, in Bulletin 45 of the Agricultural Experiment Station of Nebraska, have shown that—

of the 23.33 inches of annual rainfall in Nebraska 16.08 inches, or 69 per cent of the entire amount, falls during the five months of the growing season, April to August, inclusive. In order to show how we compare in this respect with other States the following table is introduced. It shows what per cent of the total yearly rainfall occurs in these same five months in other localities.

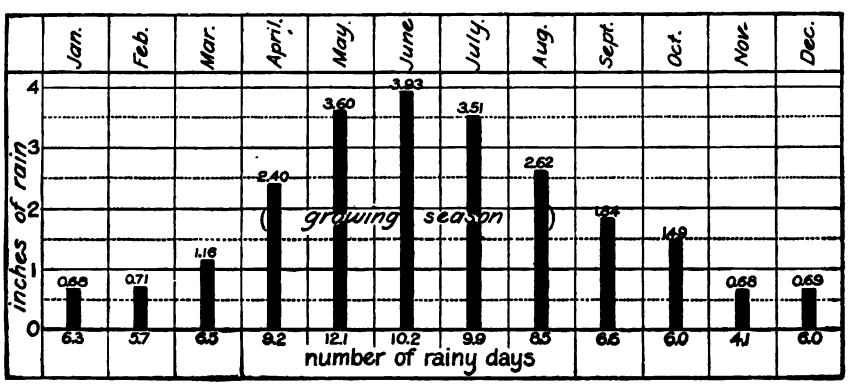


FIG. 24.—Monthly precipitation in Nebraska.

Rainfall during the growing season in various localities.

Station.	Per cent.
St. Louis, Mo	48.00
Cheyenne, Wyo	71.00
Dodge City, Kans	73.00
North Platte, Nebr	72.00
Omaha, Nebr	67.00
Huron, S. Dak	74.00
St. Paul, Minn	61.00
Duluth, Minn	57.00
Davenport, Iowa	55.00
Keokuk, Iowa	54.00
Nebraska in general	69.00

It thus appears that the States of Nebraska, Kansas, Dakota, and Wyoming, with their none too plenteous supply of rainfall, have, on the other hand, the advantage over the States lying farther to the east that a large percentage of this rainfall occurs in the growing season, when it is most useful, and that as we go eastward the percentage gradually falls off, particularly toward the southeast, or, in other words, in the direction toward which the actual amount of rainfall increases most decidedly; so that if we compare the rainfall of the growing season alone in the different localities, Nebraska does not appear in so unfavorable a light as her small yearly rainfall would indicate.

Table showing the annual precipitation in Nebraska and other States.

States.	Inches.
Indiana, to 1894	39.70
Illinois	38.05
Iowa	34.88
Kansas	26.67
Kentucky	45.60
Michigan, to 1896	30.83
Missouri, to January, 1895	37.74
Nebraska	23.33
Six New England States, to 1896	44.51
New York	37.52
North Dakota	18.88
Ohio, fifteen years to 1896	39.46
South Dakota, to 1896	19.97
Wisconsin	32.06
Wyoming, five years to 1896	13.35

SURFACE WATER AVAILABLE FOR IRRIGATION.

The first writer of prominence in Nebraska who advocated irrigation was Mr. Lewis E. Hicks, at that time professor in the University of Nebraska. His paper aroused such vehement opposition from the country press of the State at large that his position in the university was threatened. His opponents even went so far as to threaten the university itself. Hon. William R. Akers, secretary of the State board of irrigation, was among the first to put the question to a practical test, although in the face of open and avowed opposition, by building an irrigation plant in the fall of 1887. Since that time the growth of irrigation in Nebraska has scarcely been surpassed elsewhere; many miles of ditches have been built and many acres of otherwise sterile land brought under cultivation. There are at present in the office of the State board of irrigation 1,000 claims and applications, covering a total acreage of more than 4,375,321 acres for which water is claimed, the increase in land values amounting to ten to twelve million dollars.

Irrigation, wherever it is practicable, settles the matter of subsistence, for it supplies the one and only lacking soil constituent. But expectations must be kept within the bounds of reason, for there is a natural limit to this important element of our soil fertility, because the total supply of available surface water is sufficient to cover but 5,723 square miles, according to careful computation made by Prof. O. V. P. Stout—an area about equal to the combined areas of Scotts Bluff, Banner, Kimball, and Cheyenne counties. Though large, the relative insignificance of this tract as compared with the 77,000 square miles of the State is apparent. This area may be increased somewhat by pumping water from underground sources, which promises most encouraging results.

The development of windmills and other water lifters of all sorts for purposes of irrigation has been also almost as phenomenal as that of the growth of ditches themselves during the last four years, and, because of their wider applicability, bids fair to be of even greater usefulness.

SUPPLY FOR TOWNS AND CITIES.

Surface water, which is an important source of city supply in many of the Eastern States where rivers are perennial and lakes abound, is of little consequence for city and village use in Nebraska, for the obvious reason that few lakes (except ponds) exist and perennial rivers and streams are few. Accordingly but little surface water is furnished for cities and towns, and thus the use of water which must suffer steady and progressive deterioration and contamination is avoided.

The cities and towns along the lower reaches of streams are not condemned to the fate of using the sewage and filth contributed by

settlements above, nor of obtaining water from the same lake which receives their offal. Instead, the supply is ground water of almost inexhaustible quantity and superior quality, found in deep, gravelly soils, where extensive sheets of clay preclude the possibility of pollution by surface matter. It is safe to state that this is and must continue to be the source of supply alike for city and country homes.

Cisterns are often built to catch soft water for the bath and laundry, but the use of such water for drinking is very limited. Although the ordinary well water of most of the State is hard, it is not injurious. The hardness is due to lime in solution. Neither is the yellow and turbid water, which has given the Missouri the fitting appellation "The Great Muddy," necessarily injurious. The color is due to clay in mechanical suspension in the water, and its presence affects its appearance rather than its healthfulness. Such inorganic particles can be taken into the system without fear.

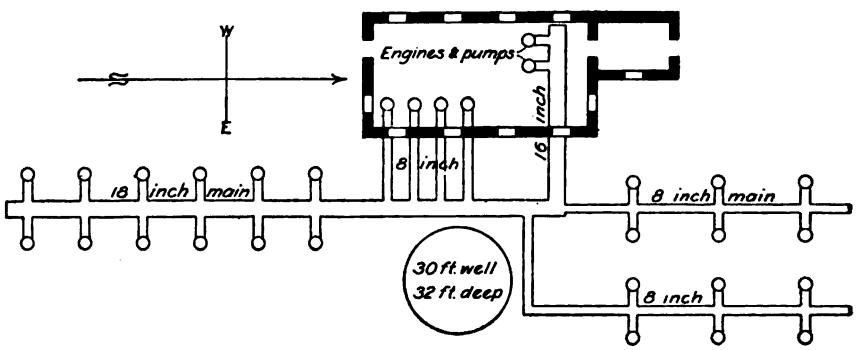


FIG. 25.—Plan of waterworks at Kearney, Nebraska.

The natural and simplest method is to draw city water supplies from streams, as is done in the case of Omaha, where the water is taken from the Missouri far above the city and allowed to stand in settling basins, whence it is pumped into the city mains. Notwithstanding prejudice against the milky color of this water, there is no reason for condemning it, for the upper reaches of this river are still so sparsely settled that the present pollution is unimportant. Interior towns far from any stream, working on the plan that if one well can supply the individual many such can supply a community, dig and connect gangs of wells. On this plan excellent water is furnished to the citizens of Lincoln, Hastings, Kearney, and smaller towns.

Kearney is in the Platte Valley, 22 feet above the level of the river, where an inexhaustible underflow can be had even in shallow wells. From one large 30-foot well, 32 feet deep, and twenty-four tubular wells a supply of water is obtained which can not be lowered and whose quality has given entire satisfaction. (See Pl. XXVI and fig. 25.) This is a source of pure water that can be depended on for years to come.

WATERWORKS AT KEARNEY, NEBRASKA.

At Hastings a 10-inch well, 305 feet deep, yields 40,000 gallons per hour for city use.

The water supply of Lincoln is pumped at three stations—the Rice pumping station, the F street pumping station, and the South street pumping station—from gangs of tubular wells. The Rice pumping station, which furnishes the best water in the city, is situated in the Antelope Valley, at M and Twenty-fifth streets. Water is obtained here from a gang of fifteen tubular wells—in the Dakota Cretaceous—averaging about 135 feet in depth, which supply about 1,200,000 gallons per twenty-four hours.

Mr. Ferdinand Bonstedt, the city engineer, thinks that he notices a slight decrease in the amount of water yielded by these wells. At the F street pumping station a large open well, 50 feet wide by 60 feet deep, was dug through one layer of water-bearing gravel down through clay to a second water-bearing gravel of rapid delivery. In order to increase the water supply a 6-inch tubular well was sunk in the middle of the open well to a depth of 15 feet, and artesian water was struck, but, unfortunately, it proved to be saline. The pipe was capped, but the saline water was under sufficient pressure to force a passage along the sides of the tubing and thence into the open well, rendering the water so salt that a boiler-steel caisson, 5 feet in diameter, was settled around it, and this is pumped out as filled. Nevertheless, the water of this station has grown more salt from year to year, and the well must be abandoned.

About a mile south of this, in the same valley, is the South street station, with a rather complex gang of sixty-eight wells, yielding 1,000,000 gallons per day. Here, too, the salinity of the water has increased to such an extent that the plant is virtually condemned, and test wells are being bored in other parts of the city in the hope of finding water equal in quality to that furnished by the Rice station.

West of Lancaster County there is little fear of encountering saline water unless city wells are dug to unusual depths, although as far west as Hastings, in Adams County, saline water was found at about 1,000 feet in 1887, and the well was necessarily abandoned.

SALT WATER.

Throughout southeastern Nebraska salt wells are so numerous that it is often uncertain how to avoid them. In pools, surface wells, and deep wells a strong brine is often met. The most conspicuous salt marsh is that of the extensive flat on Salt Creek, near West Lincoln, which has been retained by the State as public land.

Here at one time a considerable industry sprang up, and, as the early founders of the State had hoped, salt was produced and shipped to neighboring States. Here the early freighters to the mountains bought their supply. With the discovery of the salt beds of Kansas, however, this industry could no longer survive. This basin, which is a mile or two across, is apparently depressed below the surrounding

level, and one side has been cut away by a small drainage line. This has since been dammed so as to form a salt lake and a pleasure resort, and the basin is now occupied by a lake, which is about 1½ miles across. Numerous salt springs rise from its bottom and along its sides, thus supplying it with salt water. In addition, the abandoned test well (bored to a depth of 2,463 feet) is feeding out into it a 6-inch stream of salt water. In ordinary wells it is often found that fresh water can be drawn from the top and salt water from the bottom. The fresh water floats because of its lower density as compared with salt water. Considerable care is exercised in such cases in lowering the well bucket, so that the water may be agitated as little as possible in order to prevent the salt and the fresh water from becoming mixed. In one well the pump is so arranged as apparently to yield salt water or fresh water from the same pipe by placing one pipe inside of the other.

Wells in southeastern Nebraska in the region of the Carboniferous below a depth of 150 feet are liable to be or to become saline. Below this to a depth of 500 to 1,000 feet or more salt water is to be more or less expected. The salinity is greatest at 250 to 300 feet. It is strong at 500 feet, and the water is distinctly salt at 1,000 feet. When the deep well at Beatrice, 1,260 feet, was bored for the city supply the quantity but not the quality of water was expressly stipulated in the contract. When all the requirements were met the city refused to honor the bill because the water was salt. Losing the suit which followed, the contractor proceeded to make the best of a bad job by pulling up the pipe of this artesian well for use elsewhere. This would undoubtedly have saturated the drift of the region, and so have rendered worthless all the wells in and around Beatrice, but this was promptly averted by purchasing the pipe from the contractor. This saline well was still flowing when last visited.

The Riverview Park artesian well in Omaha, 1,060 feet deep, passed almost through the saline layer, but still is noticeably brackish.

At Lincoln a flowing well of very strong salt water was struck at a depth of 560 feet (boring continued to 1,060 feet), and is now utilized as a public fountain. At the Sulpho-saline Baths the water for the great swimming tank rises and flows by its own pressure from wells 566 feet deep. This water is very salt. The F-street and the South-street pumping stations yield water of such salinity as to cause widespread and continued complaint from the parts of the city which are supplied by these stations. Even the Rice pumping station, which furnishes water of high repute, is said to be sufficiently saline at times to cause comment, and a fear, which may not be wholly groundless, is entertained that the city water supply may grow more saline from year to year until it will become a serious question from what source to draw the supply. There has been increasing salinity in the case of two pumping stations, and their abandonment seems to

BURLINGTON BEACH, NEAR LINCOLN, NEBRASKA.

Illustrating the utilization of the saline water of the salt basin.

be but a matter of time. With but three exceptions, the salt wells are confined to those counties of southeastern Nebraska which belong to the Carboniferous.

With the failure of the salt works, due to the discovery of salt in Kansas, the salt marshes went into disuse, and stood as waste public land. Recently they have been leased from the State by an enterprising company and by damming up one side of the salt basin the water is set back about 1½ miles, making a salt lake. Pavilions, bath houses, and restaurants have been built, a small steamer and numerous sail and row boats have been added, and the whole bears the rather pretentious name of Burlington Beach (see Pl. XXVII). For inland people this becomes a pleasure and health resort of importance, and the enterprise promises to be increasingly useful and remunerative. So far as can be learned the first recognition of the hygienic possibilities of the saline water and its first utilization was by a former hotel proprietor in Lincoln, who is reported to have earned a considerable fortune, due largely to the salt baths which his hotel furnished. These salt baths were deservedly popular and enjoyed a local reputation, especially among those afflicted by rheumatism. At the present time their place is taken by the sanitarium of Doctors M. H. and J. O. Everett, called the Sulpho-saline Baths. This is an expensive and important institution, fitted with a great plunge and swimming tank 50 by 140 feet, and 4 to 10 feet deep, with baths and appliances of every description, representing an investment of $100,000. Two artesian salt wells, one 566 feet and the other 450 feet deep, fill the great tank, the water passing first through a heated coil and thence into the tank by its own pressure. This is the most important use to which salt wells in Nebraska have yet been put. In several cases the waters of salt wells are bottled and sold, thus presenting a commercial aspect. The salt well, known as the Lloyd Mineral Well, at Union, Nebraska, is one of the best known in this connection. Its depth is 500 feet and the water is raised by a gasoline engine. Another economic feature is the proposed use of this water in certain manufacturing processes.

Several firms have already visited the region and speak favorably of locating in southeastern Nebraska, where salt wells can be obtained in connection with good shipping facilities. On the Government square in Lincoln the salt water fed from a 1,060-foot artesian well is used to supply the public fountain. This water is carried away in bottles and pails because of real or imaginary curative properties, which almost any mineral water is reputed to have. The slightly saline water of the Riverview Park well at Omaha is put to a similar, though much larger use, because of the greater volume of water supplied. It supplies a public fountain in the park, from which a lively little cascade falls into a lake. The economic importance of this one well to the city of Omaha may be better judged when it is learned

that an equal amount of water supplied by the water company at the lowest possible wholesale water rate would cost the city $5,000 annually.

A rather novel if not unique method of irrigating by means of salt water is in vogue with market gardeners along Salt Creek. The water of this creek being too saline for direct application to the land, it is used to turn paddle wheels, which at sight might be mistaken for current wheels. Here is an example of the utilization of salt water in running undershot wheels and pumping fresh water for irrigation.

BLOWING WELLS.

One rather phenomenal class of wells found throughout a large portion of the State, especially south of Platte River, deserves particular notice, and is worthy of the critical and long-continued study which it is hoped it may yet receive. These wells are known by various names, "blowing," "roaring," "breathing," "singing," or "weather" wells, according to the widely separated communities in which they occur. It goes without saying that these wells are held in doubt elsewhere, but the fact of their existence is established beyond all question. In some communities, noticeably those of Jefferson County, all such wells are readily distinguished at a distance because of the mound of earth heaped up around the curbing and pump to check the wind. Frequently they are banked up with snow instead, and this soon becomes melted and riddled by numerous blowholes.

The attention of the author was first called to this matter by the numerous inquiries sent to his office for explanation of and the remedy for the freezing of well-protected pipes in wells at the apparently impossible depth of 30, 50, 60, 80, and even 120 feet below the surface. In every instance these were reported as roaring wells. There can be no possible doubt about the freezing of these pipes and but little doubt as to the cause.

Reports have come in from about twenty counties, distributed pretty evenly over the State, chiefly south of the Platte. The information is derived from landowners, farmers, well diggers, ministers, principals of schools, civil engineers, and students whose fathers own such wells, the only difference in the reports being that which arises from difference of observation. These accounts agree with personal observations. There are periods when these wells blow out for consecutive days and an equal period when they are reversed. This is tested with the flames of candles and by dropping paper, chaff, feathers, etc., into the casing to see it blown out with some force or drawn in. It is further stated that blowing often indicates high or low conditions of barometer, and that some wells blow most audibly when the wind is from the northwest, whereupon water rises to a higher level in the well than before; but when the conditions are reversed the air is drawn in, and in most reported wells the water is

lowered. Many observers notice a reverse of the current according as it is morning or evening, and according as the temperature is high or low. During the progress of a low-barometer area over one of these regions the wind is expelled from blowing wells sometimes violently and with a noise distinctly audible for several rods. Consequent to the following of a high-barometer area the blowing becomes rapidly less until the current is reversed, when the high-barometer area is central over the region.

Steam or water vapor rises from the curbing, melting the frost or snow for several inches around it. Beyond this the well may be encircled by several feet of frost from the condensed vapor. Shortly after the current is reversed the thawed circle freezes again. Water vapor, coming from the stratum of invariable temperature, in winter is warmer when expelled than is the outside air. This may explain the fact that the pipes, if not too badly frozen, are often thawed out when the well blows. It is said that commonly inhalation (which carries the surface temperature to the bottom of the well, thus freezing the pipes), precedes the phenomenon of exhalation (which carries vapor at the average temperature of about 56°, and sometimes thaws the frozen pipes).

Experience has taught the people that the blowing of their wells is premonitory of an approaching storm; hence the name "weather" wells. This is an entirely reasonable and correct observation, for the falling barometer signifies a change of weather. The blowing means a low-barometer area, the sucking a high-barometer area. It is interesting, in this connection, to notice that the periods of most pronounced or unusual exhalation or inhalation are coincident, respectively, with periods of exceptionally low and exceptionally high barometer areas. The author has sent blanks to owners of blowing wells, requesting them to report the days and hours when their wells begin to blow, when the blowing is at its maximum, when the current is reversed, and when the indraft is at its maximum. After observations covering two or three months have been received comparison will be made with the barometric chart.

Professors Loveland and Swezey, of the Signal Service Station of the University of Nebraska, have made observations on such a well in Perkins County, the owners recording the hour when the blowing or sucking began. These, when compared with the records of the barometer, were exactly coincident. The citizens have elaborated many explanations, some of them as interesting as ingenious. Some reason that the blowing is plainly due to the liberation of natural gas; that natural gas is from petroleum; that petroleum is the natural distillation from great coal fields, and staking their fortune on this original reasoning have spent no small sum, besides valuable time, in prospecting for coal. A few, noticing a change of current every twelve hours—that is, morning and evening—think the blowing wells are due

to tidal action of the sheet water, considering the sheet water as a great subterranean lake. They should recall that the effects of tides on the Great Lakes themselves is scarcely appreciable; what then could it be in the sheet water?

The phenomenon is most generally attributed to atmospheric pressure, which is probably the true but not necessarily the sole cause. The study of a representative section of wells in southeastern Nebraska is important and suggestive. Below 50 to 100 feet of soil and subsoil is a layer of dense, though thin, limestone about 4 inches in thickness. When this covering to the water-bearing gravel below is penetrated, water, under slight pressure, rises about 1 foot. The water-bearing layer is very porous and water is delivered through it readily. More or less air must always be inclosed in such, and especially between it and the roofing layer over the loose material.

It is plain that the air above and the air inclosed in the rock and gravel below are alike subject to the fluctuation of the barometer. If the surface air is rendered less dense by a low barometer, the air below will pass out by an opening, natural or artificial, until equilibrium between the rarer and the denser air is established, when they remain stationary. The reverse effect follows a high-barometer area. The author can not believe that this would account for the force displayed in the expulsion of air. Instead, the energy displayed seems due to the air forced out by the rising of the water below. Any force, barometric or otherwise, which would raise the water level in this layer would displace a certain amount of air. On the other hand, a lowering of the water table would admit a certain amount of air, but freedom of egress and ingress is retarded by the roofing layer of limestone, which is perforated here and there by an occasional well, and from such openings the air is expelled or drawn in. Confine this over a wide area, and it is apparent that a slight rise in water level would expel air from a well for several consecutive hours or even days. There is probably such close hydrostatic connection in the sheet water of the State that it is everywhere sensitive to differences of atmospheric pressure, and the difference is made sensible in certain localities by blowing or sucking wells. Awaiting the time when continued study shall have made exact explanation of this phenomenon possible, it is safe to attribute it to atmospheric pressure; but this is not the sole cause. The immediate effect is not so much the result of any one cause as of several. The observation is often repeated that wells blow and water rises appreciably when the wind is from the northwest. The wind is not so directly the cause as are the areas of low and high barometer, which travel ordinarily in this direction accompanied by more or less wind. The wind may, however, be the immediate cause in some cases, especially in those wells adjacent to Platte River, and an indirect cause in others. At times, when a strong wind from the northwest prevails for hours, its impact

against the river water—that is, the friction of the wind—is sufficient to drive the shallow water of Platte River across its bed, leaving the irrigation ditches, the sand bars, and the interlacing channels on the north side dry, while those on the south side are flooded. That is, the waters are piled up here, as it were, and equilibrium is disturbed. To that extent there must be readjustment. This is rendered sensible in the immediate vicinity by water rising in wells, at a distance by a wave of transmitted energy, which can but affect to a certain extent every portion of the underflow of the Platte. This may show itself in an appreciable rise of water and consequent displacement of air from porous strata, and an appreciable rise over a wide area might expel a large volume of air. Tests show that it is air, not gas, that is expelled. While exact records have been kept respecting blowing wells as far west as Perkins County, those farther east in Jefferson County, probably the most numerous and best known in the State, have received no critical study as yet.

Mr. Cassius A. Fisher, assistant in the department of geology, was sent to visit this region December 16, 1896, just as a low-barometer area was central over this spot, and the blowing in all the wells of the neighborhood was most pronounced. This continued in a diminishing ratio during the night and until noon the following day. Then the current was slowly reversed consequent to an approaching high-pressure area. Mr. J. M. Rohrbaugh, a student in the department, reports a blowing well on the farm of his father, Mr. C. W. Rohrbaugh, as follows: The well is situated 4 miles southeast of Jansen, in Jefferson County, sec. 1, T. 2, R. 3 east of the sixth principal meridian. The well was bored to a depth of 130 feet; depth of water 120 feet. It blows out before storms, especially when the wind is from the northwest. It has frozen repeatedly to a depth of 120 feet, that is, to the water level. Water froze in the pipes down to this depth three times in one week during the winter of 1895, and the pipe had to be removed and thawed out each time. There are two such wells, one of which has been abandoned, and over the top of the casing has been fitted a keg with a hole so bored that it whistles when the current blows out. The well sucks in air during cold weather, and then it is that pipes freeze at unusual depths.

They are of such common occurrence in Jefferson County that little is thought of the phenomenon. Mr. Rohrbaugh has furnished the author with a map showing the blowing wells near Jansen. Mr. Cassius A. Fisher reports such a well, known to him from his childhood, on the farm of his father, Mr. M. C. Fisher, six miles east of Fremont, in Saunders County. The well was 60 feet deep, and on a hillside. They called it the "singing" well, because the sound exactly resembled the singing or simmering of a teakettle. The blowing often continued for three consecutive days; at the end of that time water stood several feet higher in the well, as they could tell by lowering the well bucket.

The "breathing" well of Joseph Henggler, of Columbus, Platte County, represents very nicely this type of wells. It has been reported in person by the owner and by at least six to eight different neighbors. They have long been familiar with the fact that the air was drawn in during certain seasons and blown out during others, and with the difficulty from the freezing of the pipes; the water escape has been lowered from 10 feet, where it was first placed, to 20 feet, then to 40, and finally to 50 feet, which was about on the water level, the well being 60 feet deep. The pipe was frozen at the depth of 50 feet. Mr. Henggler has kept a thermometer by his well, and has been able to make pretty close observations. "When the temperature stands at 32° a rise of 1° will cause a current to blow out and a fall of 1° to blow in." Finding that the well was freezing, he undertook to stop the ingoing current by banking up the well curbing with manure and straw from the barn. This was soon blown away. Then straw with a layer of earth was placed over the curbing. Finally the "imprisoned wind" blew around the curbing to such an extent that it hollowed out a considerable basin. After several years the well was abandoned and a second well dug, which has caused the owner, according to his account, almost as much trouble. In Franklin County exactly similar wells are reported. An assistant has visited and reported a well near Macon which has frozen in winter to a depth of 80 feet, because of the indraft of cold air. He also reports of the same well that when the wind is from the northwest the water is raised about 18 inches, and when in the opposite direction the water is lowered about 18 inches.

In Phelps County, 3 miles north of Phelps Center, there are blowing wells in which the current of air is out or in, according as the wind is from the north and northwest or from the south and southeast. Mr. J. F. O'Brien, engineer of the irrigation canal at Kearney, has seen these wells, and has told the author personally of them and of blowing wells found in Lincoln County. According to his account he has seen numerous wells of this type, and they are usually found in loose sand and gravel south of the Platte.

INDEX.

Page.

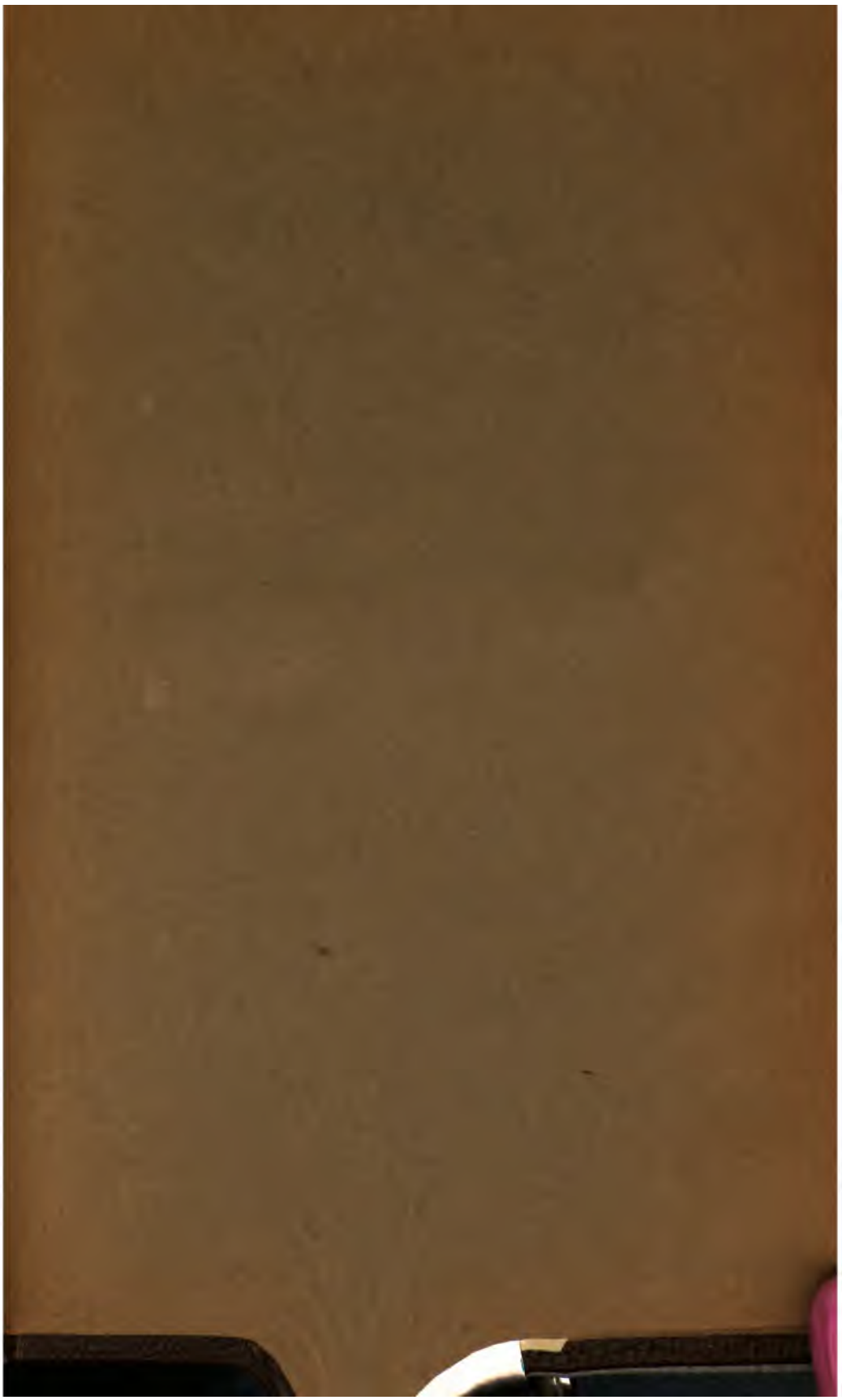
Adams County, well in 20
Ainsworth, well near 20
windmills at 41, 59–60
Alma, experiment station at 25
Artesian water, nature of 18–24
Artesian wells in Nebraska, list of 20–23
Artois, France, wells in 18
Ashland, plate showing windmill near 52, 60
windmills near 53–54, 65
Baldwin, W. F., windmill of 59–60
Battle-ax windmills, features of 47–54
figures showing construction of 40, 49, 50, 51, 52
Beatrice, wells at 19, 21
Beaver Crossing, plate showing wells at 24
wells at 19
Benkelman, water elevator near 68
Berwin, figure showing windmill at 44
Bethany, plates showing windmills near 36
windmill near 37, 39
Bird City, Kans., experiment station at 25
Blackman, E. E., windmill of 45–46
Blowing wells, features of 78–82
Boardman's windmill 38–39
Boersen, Henry, windmill of 62–63
Boiling springs, nature of 24
Bonstedt, Ferdinand, cited 75
Bormann, Henry, windmill of 55–56
Boyd County, wells in 20
Brokenbow, experiment station at 25
Breathing wells, features of 78–82
Brock, well near 22
Brown County, well in 20
Brown, J. L., windmill of 37–38
Burchard, well near 22
Burlington Beach, plate showing 76
salt wells at 77
Burt County, wells in 20
Campbell, H. W., deep plowing by 26
Capillary action of water 16
Carboniferous formation, wells in 19
Cass County, well in 21
Cattle raising, methods of 26
Cedar County, wells in 21
Chalco, plate showing windmill near 54
windmill near 54–55
Cherry County, wells in 21
Cheyenne County, well in 21
Close farming, results of 25–26
Columbus, blowing well at 82
windmill at 41
Cook, wells at and near 19, 21, 22

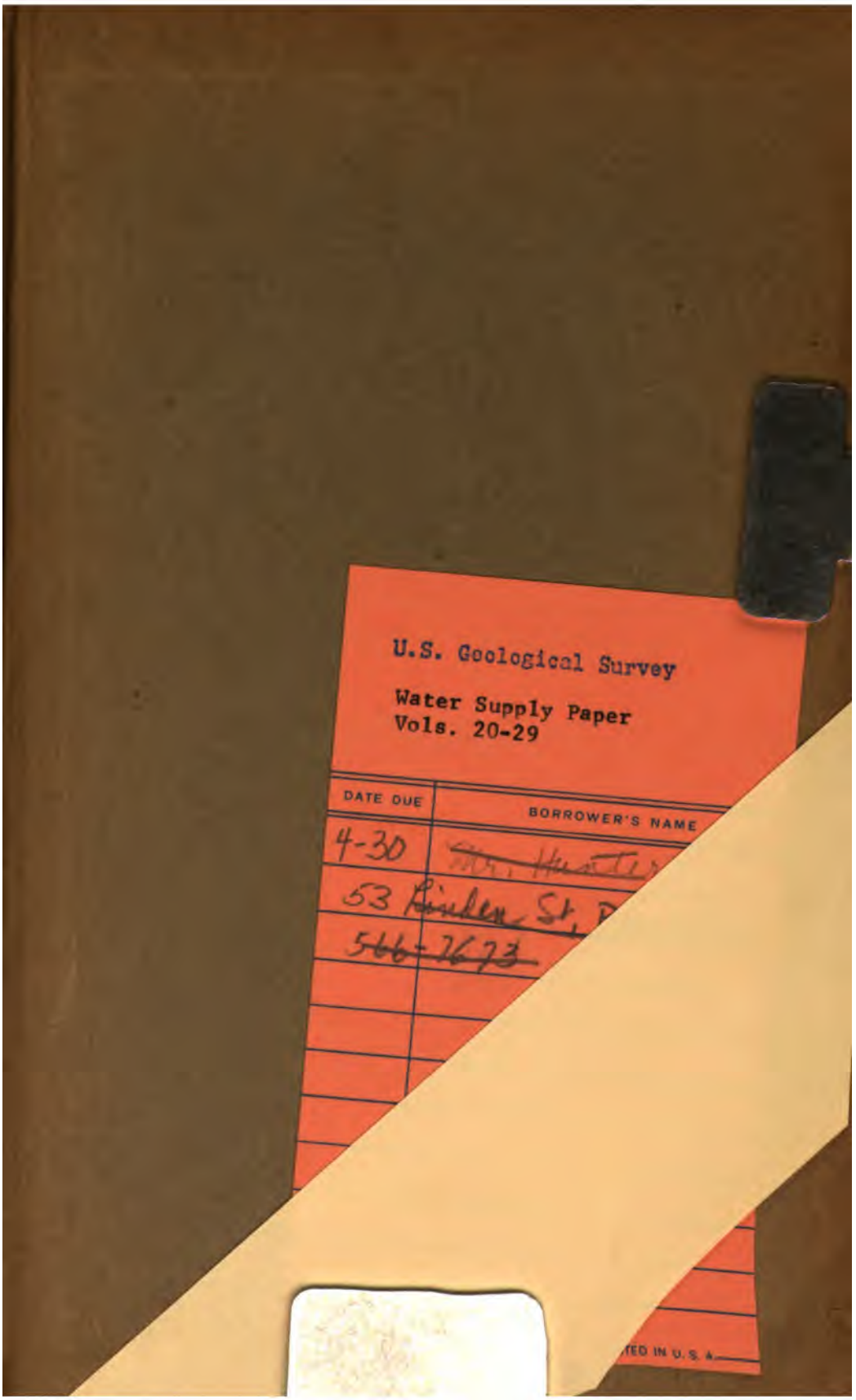
Page.

Cozad, plate showing windmill at 38
windmill at 39
Craig, well in 20
Crawford, well at 21
Crete, water elevator near 69
Cuming County, well in 21
Current wheels, features of 69
Curtis, experiment station at 25
Cushman County, plate showing windwill in 38
Dairying, use of windmill in 29–30, 31
Dakota sandstone, artesian wells in 19
Dawes County, wells in 21
Deep plowing, advantages of 26
Dixon County, wells in 21
Dodge County, well in 21
Douglas County, wells in 20
Dust-blanket farming, method of 26
Dutch windmills, features of 54–56
Elk Creek, well near 21
Elkhorn, well in 20
Endless chain, use of 44, 66, 67–68
Erina, well at 21
Ernstmeyer, Friedrich, windmill of 57
Fairmont, plate showing waterworks at 62
Fisher, C. A., work of 81
Fisher, M. C., well of 81
Franklin County, blowing well in 82
Fremont, blowing well near 81
Fullerton, well near 22
Gage County, well in 21
Gandy, well at 22
Garfield County, wells in 21
Geiss, Jacob, windmill of 48
Gering, well at 23
Go-devil windmills, features of 35–44
Goodrich, W. W., windmill of 37, 39
Gothenburg, plate showing windmill near 52
windmill near 51–53, 56
Grand Island, plates showing windmills near 48, 50, 56, 58
windmills at and near 45, 47–48, 50, 57, 62–64
Grant, experiment station at 25
Grant County, well in 21
Greeley Center, windmill at 45
Ground water, action of 14–28
Harders, John, windmill of 50
Hat Creek, current wheel on branch of 69
plate showing current wheel on branch of 68
Hastings, experiment station at 25
water supply of 74–75

	Page.
Hastings, well near	20
Havelock, windmill in	37
Henggler, Joseph, well of	82
Herman, wells at	23
Hicks, L. E., cited	73
Holdrege, experiment station at	25
Holland windmills, features of	54–56
Holt County, plate showing well in	18
wells in	19, 21
Homemade windwills, cost of	34
description of	35–64
distribution of	35, 36
types of	31–35
use of	31–34
Hood, O. P., cited	36
Hooker County, well in	21
Hooper, well near	21
Hot Springs, S. Dak., current wheel at	69
plate showing current wheel near	68
Huennecke, Diedtrich, windwill of	50–51
Hunter, David, current wheel of	69
Hyannis, well at	21
Hygroscopic water, action of	16
Iler, W. W., windwill of	37
Intensive cultivation, effects of	25–26
Irrigation, use of artesian wells in	23–24
use of water lifter in	68
use of windmills in	29–31, 39–40
water available for	73
James, William, water elevator of	69
Janak Bros., windmill of	57–59
Jansen, blowing well near	81
Jasperson, Elmer, windmill of	53–54, 65
Jefferson County, blowing wells in	78, 81
Joehnck, Henry, windmill of	45
Johnson County, artesian wells in	18
wells in	19, 21–22
Jumbo windmills, construction of	42, 44
features of	35, 42
plates and figure showing construction of	40, 42
Karr, J. W., water elevator of	68
Kearney, plan of waterworks at	74
plate showing waterworks at	74
plate showing windmill at	36
water supply of	74
windmills near	37–38, 65
Kettle Springs, nature of	24
Kirkwood, wells near	24
Knox County, well in	22
Lancaster County, wells in	20
Lincoln, plates and figure showing windmills near	38, 40, 44, 46, 64
salt wells at	76–77
water supply of	74–75
wells at and near	19, 20
windmills at and near	40–41, 46, 66
Lincoln County, blowing wells in	82
well in	22
Lena, well at	22
Logan County, well in	22
Loup County, well in	22
Loup River Valley, windmills in	35
Loveland, G. A., and Swezey, G. D., cited	71, 72, 79
Macon, blowing well near	82
Madison County, well in	22
Madrid, well near	22
Mathiesen, Fred, windmill of	57
McComb, W. F., windmill of	64
McCook, experiment station at	25
well at	23
McPherson County, wells in	22
Merry-go-round windmills, construction of	46–47
features of	44–46
figures showing construction of	45, 46
Milford, plate showing dam at	28
plate showing windmill near	66
windmill at	66
Moisture, conservation of	24–26
Moulton Ice Company, windmill of	66
Mound Springs, nature of	24
Mullen, well at	21
Nance County, well in	22
Nebraska, rainfall in	45
Nemaha County, well in	22
Newell, F. H., letter of transmittal by	11–12
Newport, windmill at	64
Norfolk, well near	22
North Platte, distribution of rainfall at	72
figure showing tympanum at	67
windmill at	66–67
Oberlin, Kans., experiment station at	25
O'Brien, J. F., cited	82
Ogallala, plate showing windmill at	60
windmills at	64–65
Olson, M. J., windmill of	39
Omaha, distribution of rainfall at	72
plate showing well at	18
salt well at	76, 77
water supply of	74
wells at and near	19, 20, 23
Ord, well near	23
Otoe County, wells in	22, 23
Overton, plates showing windmills near	48, 58
windmill at and near	38–39, 49–50, 60–62
Oxford, experiment station at	25
Paddle wheels, features of	35–44
Palmyra, well at	23
Pardee, Lewis, windmill of	64
Pawnee, well near	22
Pawnee County, wells in	22
Peckham, E. L., windmill of	51–53
Peckham, J. S., windmill of	51–53
Perkins County, blowing well in	79
well in	22
Phelps County, blowing wells in	82
Pilger, well near	23
Platte County, blowing well in	82
well in	22
Platte River, irrigation from	27–28
plate showing	28
Platte Valley, windmills in	35, 47–50, 55
Pollution of water	26–27
Polk County, well in	22
Ponca, wells near	21
Portal, plate showing windmill near	54
windmill near	55–56
Precipitation in Nebraska, amount of	71–72
figure showing	71
Prinz, August, windmill of	54–55
Pumps, disadvantages of	44
Putney, S. Dak., deep plowing at	26

	Page.
Rainfall in Nebraska, amount of	71–72
Redwillow County, well in	23
Republican Valley, windmills in	35
Roaring wells, features of	78–82
Rock County, wells in	19, 23, 24
Rohrbaugh, C. W., well of	81
St. Francis, Kans., experiment station at	25
Sarpy County, well in	23
Sarpy Mills, windmill at	57–58
Salt Creek, salt marsh on	75–76
Salt wells, location of	75–78
Saunders County, blowing well in	81
Scotts Bluff County, well in	23
Screw jumbo windmills, features of	41–42
Seepage water, utilization of	27–28, 46
Seward County, artesian wells in	18
well in	23
Sheep raising, importance of	32
Sheet water, nature of	17–18
Sidney, well near	21
Soil of Nebraska, character of	16–17
Stanton County, well in	23
Steinauer, well at	22
Storage of power, methods of	69–71
Stout, O. V. P., cited	73
Stromsburg, well at	22
Sutherland, current wheel near	69
well near	22
Swezey, G. D., and Loveland, G. A., cited	71–72, 79
Tannehill, John, windmill of	41
Taylor, well at	22
Tekamah, well in	20
Town water supply, use of windmill for	65–66
Transmission of power, figure showing method of	70
methods of	69–71
Travis Bros., windmills of	40–41
Trenton, windmill at	41
Turbine windmills, features of	47
figures showing construction of	58, 59, 60, 61, 62, 63
kinds of	47
reconstruction of	64–65
uses for	66–67
Tympanum water wheel, figure showing	67
novel uses of	66–67
Unadilla, well near	22
Underground water, action of	14–28
Union, mineral well at	77
University of Nebraska, plate showing windmill at	30
Valley County, well in	23
Videtto, S. S., windmill of	46
Warner, J. M., windmill of	60–62
Washington County, wells in	23
Water, height of	28
Water lifters, forms of	29, 67–69
Water supply for towns	73–75
Water table, height of	14–15
Weather wells, features of	78–82
Weeping Water, well at	21
Wheeler, Kans., experiment station at	25
Wheeler County, well in	23
Whitney, Milton, analyses by	16
Wilson, Matthew, windmills of	49–50
Windlasses, use of	29
Windmills, reconstruction of	64–65
uses of	29–31, 65–67
See Homemade windmills.	
Winn, William A., windmill of	45
Wisner, well at	21
Woodlake, well at	21
Woulf, Fred, windmill of	50
York, wells at	23
York County, wells in	23




U.S. Geological Survey
Water Supply Paper
Vols. 20-29
DATE DUE
BORROWER'S NAME
4-30
53 Rinker St, P
566-7673